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14. ABSTRACT  Specific Aim 1 will evaluate the efficacy of the Eagle Tactical Athlete Program (ETAP) to mitigate unintentional musculoskeletal injuries. Specific Aim 2 will evaluate the efficacy of ETAP, as delivered by NCO/ICS certified instructors, to improve laboratory, performance, and APFT testing. Specific Aim 3 will prospectively identify risk factors for unintentional musculoskeletal injuries in the 101st Airborne Division (Air Assault) Soldier.					
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## INTRODUCTION

In 2003, the Department of Defense and the Armed Forces Epidemiological Board identified musculoskeletal injury prevention research as a necessary focus. Unintentional musculoskeletal and overuse injuries during tactical operations training, combat, and physical training are a principal health concern in the military given the considerable investment per Soldier. Soldiers of the 101st Airborne Division (Air Assault) have been described as tactical athletes given the functional demands of operational training and combat. Considering the vigorous demands of tactical operations training, combat, and physical training, implementation of a 101st Soldier-specific injury prevention and performance optimization training research initiative was warranted. The purpose of this multi-aim research initiative was to systematically and scientifically address the current injury prevalence to 101st Airborne Division (Air Assault) Soldiers, identify modifiable injury risk factors, and optimize physical readiness.

The 101st Airborne (Air Assault) Injury Prevention and Performance Optimization Program is a joint research project between the University of Pittsburgh, Department of Sports Medicine and Nutrition, and the Division Command, Division Surgeon, and Blanchfield Army Community Hospital of the US Army 101st Airborne Division (Air Assault) at Fort Campbell. This project is funded by the United States Department of Defense and is under the auspices of US Army Medical Research and Materiel Command/Telemedicine and Advanced Technology Research Center (*Injury Prevention and Performance Optimization in 101st Airborne Soldiers*, W81XWH-06-2-0070, W81XWH-09-2-0095, W81XWH-11-2-0097).

## BODY

### Award Period of Performance

- A no cost extension was approved 14 OCT 11. New expiration is 23 FEB 13.

### Project Overview

#### **Specific Aim 1: To evaluate the efficacy of the Eagle Tactical Athlete Program (ETAP) to mitigate unintentional musculoskeletal injuries**

ETAP was formally phase implemented into Division physical training as part of W81XWH-09-02-0095/W81XWH-11-2-0097. Following the format of the ICS pilot, Division implementation of ETAP involved a two-step process including, Instructor Certification School (ICS) and unit exposure. For the period of the last 12 months, 30 classes of Soldiers were enrolled in ICS (430 Soldiers). ETAP was extended from the validated eight week format to a monthly periodized program to be performed during predeployment training. The monthly program contained the same principles by which the eight week model was developed, but modified the progression of each training modality to account for the longer duration (deployment schedule-dependent). The weekly training format was the same with individual days dedicated to a single training principle with allowances built into the program to account for combat focus training. An estimated 8,640 Soldiers have been exposed to ETAP as their physical training for the last year.

Monitoring of unintentional musculoskeletal injuries was implemented to test the efficacy of ETAP to mitigate injuries during garrison and deployment. A clinical trial design was implemented to compare injury rates between an experimental and control group. Soldiers enrolled were selected because of their commonality in tactical missions (considered like units) and deployment to same theater.

Investigators worked with personnel from the Armed Forces Health Surveillance center and identified specific data sets for query including ICD9 codes, date range of analysis, and breakdown of enrolled subjects. The extraction resulted in 21,454 records for analysis of 2105 subjects. The data are currently being transformed for analysis and under review by our biostatistician/epidemiologist.

The investigators also worked with personnel from Tricare Management Activity (TMA) to identify specific data sets for query including ICD9 codes, date range of analysis, and breakdown of enrolled subjects for the respective data set. The data query has been approved and will be queried by TMA and analyzed once received.

**Specific Aim 2: To evaluate the efficacy of ETAP, as delivered by NCO/ICS certified instructors, to improve laboratory, performance, and APFT testing**

Soldiers of the 159CAB were enrolled to confirm knowledge transfer and compliance, progression, and establish long term effects of ETAP on performance when implemented by the certified NCO/ICS instructors. Baseline and the first interval tests were performed on 51 Soldiers following ICS implementation under W81XWH-09-2-0095. Post-deployment data will be captured upon the return of the enrolled units scheduled for late February/March 2012.

**Specific Aim 3: To prospectively identify risk factors for unintentional musculoskeletal injuries in the 101st Airborne Division (Air Assault) Soldier**

As a continuation of W81XWH-09-2-0095 injury data were captured from AHLTA by the personnel of Blanchfield Army Community Hospital. Data records were extracted at an estimated rate of 30 per month for a total of 330 records. Data were extracted for 18 months prior to and 12 months following laboratory testing. Upon receipt of the file from BACH, each subject's data were entered into the University of Pittsburgh Medical Epidemiology Database for analysis. Data will continue to be extracted from AHLTA until 31 OCT 12. Injury data will be analyzed in conjunction with laboratory data to identify potential risk factors for unintentional musculoskeletal injuries in 101st Airborne Division (Air Assault) Soldiers. To date,

**Expanded Research Activities**

- The investigators met with the new 101st Airborne Division (Air Assault) Command to outline calendar year 2012 activities which represent the final year of research for the University of Pittsburgh. This briefing included completion of current research aims and introduction of the Soldier Fueling Initiative and ETAP/PRT comparison trial. Based on this meeting the Command was not supportive of expanding our research to include testing of the Soldier Fueling Initiative or ETAP/PRT trial. The Command was concerned of the extra burden placed upon the Soldiers from competing aims as intensive training cycles are initiated.
- The Command requested greater oversight of ETAP implementation with "mobile units" added to Instructor Certification School. Mobile units will work directly with unit physical training to ensure implementation quality due to Command turnover following redeployment.
- The last request to the Army Physical Fitness School for status on involvement was not answered. Based on Command's response and lack of collaborative effort from the Army Physical Fitness School, the investigators recommend completion of Specific Aims 1-3 as outlined until award termination.

**Personnel**

Personnel changes included the addition of Mr. Gordon Huang, MS, PT (Research Associate- Neuromuscular Research Laboratory, University of Pittsburgh) and Mr. Eric Hughes (Intern- Youngstown State University). Mr. Tony House, MS, ATC was removed from the protocol.

**Human Subjects Protections**

Human subject protections compliance is maintained by review boards from the University of Pittsburgh and Dwight D. Eisenhower Army Medical Center, and higher level review performed by Clinical Investigation Regulatory Office and Office of Research Protections, Human Research Protection Office (HRPO). All approvals are current with HRPO renewals due 29 FEB 12. Approval letters are attached.

**KEY FY 10 RESEARCH ACCOMPLISHMENTS**

- Identified relationship between self-reported and medical-chart reviewed data for completeness of injury history

- Identified impact of load carriage/visual input on postural stability and biomechanical performance
- Identified supplement usage habits of Soldiers
- Completed enrollment of Soldiers into Specific Aim 1 (2105 subjects)
- Completed Instructor Certification School class 100 and enrollment of 1500 Soldiers
- Data extraction from the Armed Forces Health Surveillance Center completed and in analysis
- Gained approval from Tricare Management Activity for data query

## **REPORTABLE OUTCOMES**

### **Abstracts**

#### **Accepted**

Kim Crawford, Matt Darnell, Heidi Stapel, Mita T. Lovalekar, John P. Abt, Timothy C. Sell, Larry J. McCord, Michael D. Wirt, Takashi Nagai, Jennifer B. Deluzio, Scott M. Lephart, FACSM. Dietary Supplement Habits of Soldiers of 101st Airborne Division Air Assault. 2012 American College of Sports Medicine. May 29 – June 2, 2012; San Francisco, CA.

Clark NC, Keenan KA, Abt JA, Sell TC, Nagai T, Deluzio JB, Lovalekar MT, McCord LJ, Wirt MD, Lephart SM. Clinically Significant Side-to-Side Lower Extremity Strength Asymmetries in US Army 101st Airborne Soldiers. 2012 American College of Sports Medicine. May 29 – June 2, 2012; San Francisco, CA.

#### **In Review**

Lovalekar M, Abt J, Sell T, Nagai T, Deluzio J, Wirt M, Lephart S. Measuring self-reported recall of unintentional musculoskeletal injuries in an Army Airborne Division. 140th Annual Meeting & Exposition of the American Public Health Association; October 27-31, 2012; San Francisco, CA.

#### **Not Accepted**

Sell TC, Pederson JJ, Nagai T, Lovalekar MT, Abt JP, McCord LJ, Wirt MD, Lephart SM. The Addition of Body Armor Alters Dynamic Postural Stability. 2012 American College of Sports Medicine. May 29 – June 2, 2012; San Francisco, CA.

#### **Presented**

Lovalekar M, Abt J, Sell T, House A, Nagai T, Pederson J, Lephart S. Comparison of self-reported musculoskeletal injury history between female and male US Army Soldiers. 139th Annual Meeting & Exposition of the American Public Health Association; October 29 - November 2, 2011; Washington, DC.

Keenan KA, Abt JP, Sell TC, Nagai T, House AJ, Deluzio JB, Smalley BW, Lephart SM. Strength Differences Between Male and Female Soldiers of the 101st Airborne Division (Air Assault). 2011 Annual Meeting and Clinical Symposia of the NATA. June 19-22; New Orleans, LA.

Crawford K, Darnell ME, Abt JP, Sell TC, Lovalekar MT, House AJ, Smalley BW, Lephart SM. Dietary Habits of Soldiers of 101st Airborne Division Air Assault. 2011 American College of Sports Medicine. May 31-June 4; Denver, CO. May 31-June 4.

Darnell ME, Crawford K, Abt JP, Sell TC, Nagai T, House AJ, Deluzio JB, Smalley BW, Lephart SM. Dietary Intake of Army Soldiers in Occupation Specialties Requiring Heavy Physical Demands. 2011 American College of Sports Medicine. May 31-June 4; Denver, CO.

Keenan KA, Sell TC, Abt JP, Crawford K, House AJ, Smalley BW, Abt JP, Cardin S, Lephart SM. Physiological Differences Between Male and Female Army Soldiers Matched on Age and Years of Service. 2011 American College of Sports Medicine. May 31-June 4; Denver, CO.

Abt JP, Sell TC, Nagai T, Deluzio JB, Lovalekar MT, Crawford K, Smalley BW, Lephart SM. Deployment-related changes in physical and physiological characteristics. 2011 American College of Sports Medicine.

May 31-June 4; Denver, CO.

Nagai T, Abt JP, Sell TC, Deluzio JB, Lovalekar MT, Crawford K, Smalley BW, Lephart SM. Changes in Physical and Physiological Characteristics after Deployment to Afghanistan. 2011 American College of Sports Medicine. May 31-June 4; Denver, CO.

Sell TC, Lovalekar, MT, Nagai T, House AJ, Smalley BW, Abt JP, Lephart SM. The Perception of Load Carriage as a Risk Factor for Injury in U.S. Army Soldiers. 2011 American College of Sports Medicine. May 31-June 4; Denver, CO.

### **Manuscripts**

#### **Published**

Crawford K, Fleishman K, Abt JP, Sell TC, Lovalekar M, Nagai T, Deluzio J, Rowe R, McGrail M, Lephart SM. Less Body Fat Improves Physical and Physiological Performance in Army Soldiers. Military Medicine. 2011; 176(1), 35-43.

#### **In Press**

Chu Y, Sell TC, Abt JP, Nagai T, Deluzio J, McGrail M, Rowe R, Smalley B, Lephart SM. Air-Assault Soldiers Demonstrate More Dangerous Landing Biomechanics When Visual Input is Removed. Military Medicine.

#### **In Review**

Sell TC, Pederson JJ, Abt JP, Nagai T, Deluzio JB, McCord LJ, Wirt MD, Lephart SM. The Addition of Body Armor Diminishes Dynamic Postural Stability in Military Soldiers. Military Medicine.

#### **Not Accepted**

Keenan KA, Sell TC, Abt JP, Nagai T, Deluzio JB, McGrail M, Rowe R, Smalley B, Lephart SM. Musculoskeletal, biomechanical, and physiological sex differences in the US military. Medicine and Science and Sports and Exercise.

### **Grant Submissions**

None

### **CONCLUSIONS**

In the final phase of research, three aims remain ongoing: 1) ETAP is being validated to mitigate unintentional musculoskeletal injury between an experimental and control group, 2) ETAP is being evaluated to test the efficacy of ETAP, as delivered by NCO/ICS certified instructors, to improve laboratory, performance, and 3) Prospectively identify risk factors for musculoskeletal injury that are specific to the 101st Airborne (Air Assault).

### **REFERENCES**

Not applicable

### **APPENDICES**

Attached

## **Comparison of self-reported musculoskeletal injury history between female and male US Army Soldiers**

Mita Lovalekar, MBBS, PhD, MPH, John Abt, PhD, ATC , Timothy Sell, PhD, PT , Anthony House, MS, ATC , Takashi Nagai, MS, ATC , Jonathan Pederson, ATC , Scott Lephart, PhD, ATC

**Background/ Purpose:** Musculoskeletal injuries can adversely impact performance and certain injuries are risk factors for recurrence of the injury. The aim of this analysis was to compare the proportion of female and male US Army Soldiers with a self-reported history of musculoskeletal injury.

**Methods:** Self-reported musculoskeletal injury history for a period of two years was obtained from 296 Soldiers (age =  $27.8 \pm 6.5$  years, 12.2% female). Injuries were classified according to their anatomic location and injury type (traumatic vs. overuse). Proportions of subjects with injuries were compared using Fisher's exact test.

**Results:** Age was not significantly different between genders (females  $27.0 \pm 6.0$  years, males  $27.9 \pm 6.6$  years,  $p = 0.440$ ). A greater proportion of females reported a musculoskeletal injury compared to males (41.7% and 28.1% respectively,  $p = 0.119$ ), though this difference was not statistically significant. A greater proportion of females than males reported a lower extremity injury (27.8%, 13.8%,  $p = 0.046$ ) and a knee injury (11.1%, 2.7%,  $p = 0.033$ ). There was no difference in the proportion of females and males reporting an upper extremity injury (5.6%, 7.7%,  $p = 1.000$ ). Interestingly, a greater proportion of females than males reported an overuse injury (22.2%, 8.8%,  $p = 0.036$ ).

**Conclusions:** Examination of potential physiological, musculoskeletal, biomechanical and nutritional risk factors in these subjects is necessary. There may be a need to implement a customized program to prevent recurrence of certain lower extremity and overuse injuries in female Soldiers, and to prevent an adverse impact on performance.



## Strength Differences between Male and Female Soldiers of the 101st Airborne Division (Air Assault)

Keenan KA\*, Abt JP\*, Sell TC\*, Nagai T\*, House AJ\*, Deluzio JB\*, Smalley BW†, Lephart SM\*: \*Neuromuscular Research Laboratory, Department of Sports Medicine and Nutrition, School of Health and Rehabilitation Sciences, University of Pittsburgh, Pittsburgh, PA, †101st Airborne Division (Air Assault), Fort Campbell, KY

**Context:** In the US Army, male and female Soldiers participate in gender-neutral physical training and may have similar physical demands during occupational and operational tasks. Musculoskeletal injuries, many of which may be preventable, are the primary reason for seeking medical care among military personnel and may be related to suboptimal musculoskeletal characteristics, which may result in higher injury rates in female Soldiers. **Objective:** To determine if strength differences exist between genders in US Army Soldiers of the 101st Airborne Division (Air Assault) matched on age and years of service (YOS). **Design:** Cross-sectional study. **Setting:** Research laboratory. **Participants:** Data were collected on 65 female Soldiers (age=26.9±5.7 years, height=1.65±0.06 m, mass=65.7±9.8 kg) and 65 male Soldiers (age=26.9±5.8 years, height=1.76±0.07 m, mass=82.3±12.7 kg) matched on age (±2 years) and YOS (± 1.0 years). All subjects were free of current medical or musculoskeletal conditions that prevented full active duty. **Interventions:** Isokinetic knee flexion/extension (FLEX/EXT), shoulder internal/external rotation (IR/ER), and torso rotation (ROT) strength was assessed using an isokinetic dynamometer (5 repetitions each, 60°/sec). Isometric hip abduction/adduction (ABD/ADD) strength was assessed with three, 5 sec alternating contractions using an isokinetic dynamometer. Isometric ankle inversion/eversion (IN/EV) and plantarflexion/dorsiflexion (PF/DF) strength was assessed using a handheld dynamometer (3 repetitions). All tests were performed on the right side. Paired *t*-tests were used to compare normally distributed variables and Wilcoxon signed rank tests were used to compare non-normally distributed variables. Statistical significance was set at  $p < 0.05$  *a priori*. **Main Outcome Measures:** Peak torque was averaged normalized to body weight (%BW) for: shoulder IR/ER, knee FLEX/EXT, torso ROT, and hip ABD/ADD. Average peak force (kg) was calculated for ankle IN/EV and PF/DF. **Results:** Female Soldiers demonstrated significantly less strength in shoulder IR (F: 35.8±8.9 %BW; M: 61.3±15.1 %BW), shoulder ER (F: 29.5±5.2 %BW; M: 43.7±9.7 %BW), knee FLEX (F: 92.9±20.9 %BW; M: 116.8±30.1 %BW), knee EXT (F: 189.5±36.9 %BW; M: 241.6±55.4 %BW), torso ROT (F: 105.8±25.3 %BW; M: 150.9±29.2 %BW), ankle IN (F: 25.2±6.8 kg; M: 34.3±7.5 kg), and ankle EV (F: 22.3±6.0 kg; M: 30.7±6.3 kg), (all,  $p < 0.001$ ). **Conclusions:** Strength differences do exist between male and female Soldiers, with female Soldiers demonstrating less shoulder, knee, ankle, and torso strength. No gender differences were noted in hip strength or ankle PF/DF; however it is unclear if this is due to adequate strength in female Soldiers or inadequate strength in male Soldiers and should be explored further. Future research should explore if these differences contribute to unintentional musculoskeletal injury and decreased physical readiness as well as if these differences can be mitigated through gender-specific physical training.

Supported by USAMRMC/TATRC #W81XWH-06-2-0070 and #W81XWH-09-2-0095

## **Dietary Habits of Soldiers of 101st Airborne Division Air Assault**

Kim Crawford, Matthew E. Darnell, John P. Abt, Timothy C. Sell, Mita T. Lovalekar, Anthony J. House, Brian W. Smalley, Scott M. Lephart, FACSM. University of Pittsburgh, Pittsburgh, PA., 101st Airborne Division (Air Assault), Fort Campbell, KY

Proper nutrition plays an important role in maximizing a Soldier's ability to meet the demands of physical and tactical training. **PURPOSE:** To evaluate dietary habits of 101st Airborne Division (Air Assault) (101st ABN DIV (AA)) Soldiers. **METHODS:** A total of 367 101st ABN DIV (AA) Soldiers (female 57; male n= 310; Age 27.9±6.5 years) completed a detailed diet history including eating habits, food and fluid intake before during and after physical training, and dietary supplement use. A 24 hour recall was collected (n=293; female=52, male =241) and analyzed using Food Processor SQL 10.6 (ESHA) to assess macro- and micronutrient content of the diet. **RESULTS:** Soldiers consumed 3.4±1.0 meals per day with 25% of Soldiers skipping at least one meal per day. Soldiers reported eating out 4.4±5.6 meals per week (range, 0-31 meals). Carbohydrate intake was 304±145 g/day (3.8 g/kg body weight), protein 111±57 g/day (1.4 g/kg body weight), and fat 91±53 g/day with 60% of Soldiers consumed greater than 30% of calories from fat. Fluids were consumed by 76% of Soldiers before physical training (PT), 70% during PT, and 98% following PT. Food was consumed by 30% of Soldiers before PT, whereas 93% consume food following PT (35% within 1 hour, 64% 1-2h, 1% > 3 h) with 77% eating a snack or meal with both carbohydrate and protein. Use of at least one dietary supplement was reported by 41% of the Soldiers (43% vitamin/mineral, 22% protein-energy drinks, 8% joint health, 7% nitric oxide, 5% each amino acids, antioxidants, weight loss). **CONCLUSION:** Our findings suggest that Soldiers of the 101st practice adequate hydration before, during and after exercise. It is recommended that Soldiers increase daily carbohydrate and protein intake and reduce total fat intake, eat at least 3 meals per day, including either a meal or snack prior to PT to optimize performance. Although the majority of Soldiers consume a sufficient post training snack to aid in recovery, low daily carbohydrate intake does not promote maximal fuel restoration. Future research should focus both on evaluating the macronutrient content of the diet that optimizes Soldier performance and on approaches to educate Soldiers on how to incorporate these nutrition guidelines into their daily eating.

Supported by USAMRMC/TATRC #W81XWH- 06-2-0070/W81XWH-09-2-0095.

## Physiological Differences between Male and Female Army Soldiers Matched on Age and Years of Service

Karen A. Keenan, Timothy C. Sell, John P. Abt, Kim Crawford, Takashi Nagai, Anthony J. House, Brian W. Smalley, Sylvain Cardin, Scott M. Lephart, FACSM  
University of Pittsburgh, Pittsburgh, PA, 101st Airborne Division (Air Assault), Fort Campbell, KY

US Army Soldiers must optimize physical readiness to minimize the risk of unintentional musculoskeletal injury and optimize performance. All Soldiers follow similar physical training (PT) guidelines and perform gender-integrated PT. In order to optimize performance, male and female athletes train differently; therefore it is possible that traditional PT may not specifically address the unique physical and physiological needs of female Soldiers. **PURPOSE:** To determine if physiological differences exist between genders in US Army Soldiers of the 101st Airborne Division (Air Assault), controlling for age and years of service (YOS). **METHODS:** Data were collected on 53 female Soldiers (age=  $25.8 \pm 4.4$  years, height=  $1.65 \pm 0.06$  m, mass=  $65.9 \pm 10.3$  kg) and matched with 53 male Soldiers (age=  $25.5 \pm 4.2$  years, height=  $1.76 \pm 0.06$  m, mass=  $83.5 \pm 13.6$  kg) based on age ( $\pm 3$  years) and YOS ( $\pm 0.5$  years). Variables analyzed were: percent body fat, total mass, lean mass, and fat mass; anaerobic power (AP)/capacity (AC); and maximal oxygen uptake (VO<sub>2</sub>max)/lactate threshold (LT). Paired *t*-tests were used to compare all variables between genders. Statistical significance was set at  $p < 0.05$  *a priori*. **RESULTS:** Female Soldiers demonstrated significantly higher %BF (F:  $27.4 \pm 6.0\%$ ; M:  $21.2 \pm 8.4\%$ ) and significantly lower total mass (F:  $65.9 \pm 10.3$  kg; M:  $83.5 \pm 13.6$  kg), lean mass (F:  $47.6 \pm 6.4$  kg; M:  $65.0 \pm 8.0$  kg), AP (F:  $9.3 \pm 1.4$  W/kg; M:  $13.6 \pm 2.0$  W/kg), AC (F:  $5.9 \pm 1.1$  W/kg; M:  $7.8 \pm 0.9$  W/kg), VO<sub>2</sub>max (F:  $39.6 \pm 5.4$  ml/kg/min; M:  $46.6 \pm 7.0$  ml/kg/min), and VO<sub>2</sub> at LT (F:  $33.3 \pm 5.3$  ml/kg/min; M:  $38.2 \pm 7.0$  ml/kg/min), (all,  $p < 0.001$ ). **CONCLUSIONS:** Gender differences in physiological variables do exist in US Army Soldiers of the 101st Airborne Division (Air Assault). These differences have important implications for potential changes or augmentation to current PT in order to optimize physical performance. Future research should investigate other physical characteristics that may relate to injury and if targeted PT that addresses the identified suboptimal characteristics in female Soldiers mitigates the risk of unintentional musculoskeletal injury and optimizes physical readiness. Supported by USAMRMC/TATRC #W81XWH-06-2-0070 and #W81XWH-09-2-0095

## Deployment-Related Changes in Physical and Physiological Characteristics

John P. Abt, Timothy C. Sell, Takashi Nagai, Jennifer B. Deluzio, Mita T. Lovalekar, Kim Crawford, Brian W. Smalley, Sylvain Cardin, Scott Lephart FACSM. University of Pittsburgh, Pittsburgh, PA, 101st Airborne Division (Air Assault), Fort Campbell, KY

Lack of standard or consistent physical training performed by Soldiers during deployment impacts physical readiness preparation. Constraints reported by Soldiers include physical demand and fatigue due to tactical requirements, lack of available time, environmental conditions, and limited or austere facilities.

**PURPOSE:** To assess deployment-related changes in physical and physiological characteristics.

**METHODS:** A total of 23 active duty Soldiers from the 101st Airborne Division (Air Assault) participated (Age:  $26.0 \pm 5.8$  years; Height:  $178.8 \pm 6.4$  cm; Mass:  $80.3 \pm 12.8$  kg; Pre Test-Deployment:  $139 \pm 17$  days; Deployment:  $433 \pm 15$  days; Deployment-Post Test:  $30 \pm 20$  days). Pre and post deployment testing consisted of assessments of body mass (kg) and body composition (%BF), isokinetic knee flexion/extension strength (%BW), and anaerobic power/capacity (W/kg). A paired t-test was used to evaluate deployment related changes in the dependent variables. Variability was calculated for each measure to determine individual subject response.

**RESULTS:** Body mass (Pre:  $80.3 \pm 12.8$  kg, Post:  $83.2 \pm 13.6$  kg,  $p = 0.02$ ) and anaerobic capacity (Pre:  $7.7 \pm 0.8$  W/kg, Post:  $7.4 \pm 1.0$  W/kg,  $p = 0.019$ ) were worse post deployment. Knee flexion strength improved post-deployment (Pre:  $112.3 \pm 23.2$ , Post:  $127.5 \pm 23.7$ ,  $p = 0.002$ ). No changes were noted for body composition, knee extension strength, or anaerobic power ( $p > 0.05$ ). The individual subject response for body mass was 22.4% loss – 26.9% gain, body composition was 30% loss – 70.3% gain, knee extension strength was 18.3% loss – 58.7% gain, knee flexion strength was 23.5% loss – 59.1% gain, anaerobic power was 33.1% loss – 32.0% gain, and anaerobic capacity was 23.6% loss – 10% gain.

**DISCUSSION:** Self-reported constraints may be weighted for each Soldier and impact the ability to perform physical training independently given large post deployment response variance. At the minimum a maintenance program should be performed to prevent diminished physical readiness while deployed. Post deployment changes in physical and physiological characteristics and self-reported constraints were considerations for development of the Eagle Tactical Athlete Program for the 101st Airborne Division (Air Assault).

Supported by USAMRMC/TATRC #W81XWH-06-2-0070/ W81XWH-09-2-0095

## **Changes in Physical and Physiological Characteristics after Deployment to Afghanistan**

Takashi Nagai, John P. Abt, Timothy C. Sell, Anthony J. House, Jennifer B. Deluzio, Mita T. Lovalekar, Kim Crawford, Brian W. Smalley, Scott M. Lephart FACSM.

University of Pittsburgh, Pittsburgh, PA, 101st Airborne Division (Air Assault), Fort Campbell, KY

Soldiers of the 101st Airborne Division (Air Assault) have experienced multiple deployments in recent years. Deployment missions and combat environment change constantly for each deployment. It is essential to understand the physical and physiological impact of deployment.

**Purpose:** To assess changes in physical and physiological characteristics during deployment to Afghanistan.

**Methods:** A total of 35 active duty Soldiers from the 101st Airborne Division (Air Assault) volunteered (Age:  $24.8 \pm 4.9$  years; Height:  $174.4 \pm 8.6$  cm; Mass:  $76.6 \pm 13.7$  kg; Pre Test-Deployment:  $207 \pm 76$  days; Deployment:  $350 \pm 18$  days; Deployment-Post Test:  $19 \pm 18$  days). Testing consisted of body mass (kg), body composition (%BF), eyes-closed single-leg balance (N), knee flexion/extension and ankle inversion/eversion strength (%BW), anaerobic power/capacity (W/kg), and aerobic capacity (ml/kg/min) and lactate threshold (%VO<sub>2</sub>max). Paired t-tests with p-value of 0.05 were used for statistical analysis.

**Results:** Anaerobic power (Pre:  $11.7 \pm 2.5$  W/kg, Post:  $12.5 \pm 2.6$  W/kg,  $p = 0.019$ ) and lactate threshold (Pre:  $77.1 \pm 8.9$  %VO<sub>2</sub>max, Post:  $82.0 \pm 7.7$  %VO<sub>2</sub>max,  $p = 0.016$ ) increased significantly post-deployment. Eyes-closed single-leg balance in medial-lateral direction (Pre:  $7.9 \pm 3.6$  N, Post:  $9.7 \pm 5.8$  N,  $p = 0.032$ ) and isometric ankle eversion strength (Pre:  $42.8 \pm 9.6$  %BW, Post:  $36.4 \pm 7.0$  %BW,  $p = 0.001$ ) worsened significantly post-deployment.

**Conclusions:** The current study has demonstrated changes during an Afghanistan deployment for various physical and physiological characteristics. Soldiers could utilize the results of this study to augment training prior to and while deployed. Specific exercises such as balance and ankle strengthening exercises may minimize the physical and physiological changes and assist with musculoskeletal injury prevention while deployed.

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## **Dietary Intake of Army Soldiers in Occupation Specialties Requiring Heavy Physical Demands**

Darnell, Matthew E.<sup>1</sup>; Crawford, Kim<sup>1</sup>; Abt, John P.<sup>1</sup>; Sell, Timothy C.<sup>1</sup>; Nagai, Takashi<sup>1</sup>; House, Anthony J.<sup>1</sup>; Deluzio, Jennifer B.<sup>1</sup>; Smalley, Brian<sup>2</sup>; Lephart, Scott M. FACSM<sup>1</sup> <sup>1</sup>University of Pittsburgh, Pittsburgh, PA. <sup>2</sup>101st Airborne Division (Air Assault), Fort Campbell, KY.

Training and operational demands of Soldiers have been likened to those of elite athletes, with similar performance and nutrition needs. Dietary recommendations have been developed for the optimal amount of carbohydrate (CHO), protein (PRO), and fat to fuel athletes involved in heavy physical training. The same recommendations may be used as a guide for soldiers with high physical demands to ensure proper nutrition to optimize physical readiness, performance, and health.

**PURPOSE:** To evaluate the dietary intakes of Soldiers with a military occupation specialty (MOS) requiring heavy physical demands.

**METHODS:** A total of 205 Soldiers of the 101st Airborne Division (Air Assault) volunteered (age: 26.5±5.4 years, height: 1.74±0.08 m, weight: 80.7±14.2 kg). All soldiers had a MOS with a physical demands rating (PDR) of moderately heavy to very heavy and completed a 24 hour diet recall. Army Pamphlet 611-21 served as the reference for PDR of specified MOS. Intake was assessed using a dietary analysis software program. Data was reported using median and interquartile range (Q1-Q3).

**RESULTS:** Calorie (CAL), PRO, CHO, and fat intake was 2,433 kcal (1,772.5-3,048.5 kcal), 101g (76-136g), 279g (195.5-378.5g), and 82g (55-112g) respectively. Soldiers consumed 17% (14-21%) of CAL from PRO, 49% (42-58%) of CAL from CHO, and 33% (25.5-38%) of CAL from fat. The amount of PRO consumed per kg of body weight was 1.29 g/kg (0.90-1.69g/kg) and CHO consumed per kg of body weight was 3.6 g/kg (2.55-4.85g/kg). Ninety percent of Soldiers fell below the recommended CHO intake of at least 7g/kg of body weight (recommendation for individuals engaging in 1-1/2 hours training per day), 87% fell outside the recommended PRO intake of 1.6-1.7g/kg body weight, and 60% consumed >30% of their CAL from fat.

**CONCLUSIONS:** These results indicate that Soldiers in a MOS with heavy physical demands may be sub-optimally fueling to meet nutrition needs. To optimize physical readiness, performance, and health Soldiers need to consume enough CHO and PRO to support training and tactical demands while at the same time reducing fat intake. Future research should examine the best methods to modify eating habits to meet the demands of physical training to optimize health, performance, and physical readiness.

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## **The Perception of Load Carriage as a Risk Factor for Injury in U.S. Army Soldiers**

Sell, Timothy C.<sup>1</sup>; Lovalekar, Mita T.<sup>1</sup>; Nagai, Takashi<sup>1</sup>; House, Anthony J.<sup>1</sup>; Smalley, Brian W.<sup>2</sup>; Abt, John P.<sup>1</sup>; Lephart, Scott M. FACSM<sup>1,1</sup> University of Pittsburgh, Pittsburgh, PA. <sup>2</sup>101st Airborne Division (Air Assault), Pittsburgh, PA.

The prevention of musculoskeletal injury is a principal concern of clinicians who care for military servicemen and the commanders responsible for their well-being. Anecdotal reports indicate that Soldier load carriage may contribute to injury, but epidemiological evidence is lacking.

**PURPOSE:** To survey Soldiers about the circumstances of their injury and perception of load carriage as a contributor to musculoskeletal injury.

**METHODS:** Self-reported musculoskeletal injury data were collected on 207 Soldiers of the U.S. Army's 101st Airborne Division (Air Assault). Soldiers were asked to provide a historical account of all injuries and answer specific questions about load carriage. Questions included whether they were carrying load; when the injury occurred; the amount/type of load; the time duration that load was worn prior to the injury; and whether they considered load carriage as a contributor to the injury.

**RESULTS:** A total of 207 injuries occurred during organized military activities. The average number of injuries reported per Soldier was  $1.0 \pm 1.3$ . Fifty-eight Soldiers reported that they were carrying load when one or more of their injuries occurred. Soldiers reported that 77 of the 207 (37.2%) injuries occurred while they were carrying a load; of these load-associated injuries, 24.7% (19/77) occurred during deployment. The majority of these injuries (61/77, 79.2%) were to the lower extremity or spine. Soldiers indicated that carrying a load contributed to their injury in 56 of the 77 cases (72.7%). According to the Soldiers, the total weight of their load was  $81.5 \pm 53.9$  pounds ( $44.5 \pm 27.1$  % body weight). In 25 of the injuries, load was worn each day on average 1 to 4 hours prior to injury.

**CONCLUSIONS:** A large proportion of injuries occurred while Soldiers were carrying load with Soldiers indicating that load carriage contributed to injury in a majority of these cases. Although load carriage as a specific risk factor for injury has not been established, it is a possible contributor, and warrants more detailed examination. Special consideration should be given to the prevention of injuries during deployment due to environmental conditions and geography.

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## Dietary Supplement Habits of Soldiers of 101<sup>st</sup> Airborne Division Air Assault

Kim Crawford, Matt Darnell, Heidi Stapel, Mita T. Lovalekar, John P. Abt, Timothy C. Sell, Larry J. McCord, Michael D. Wirt, Takashi Nagai, Jennifer B. Deluzio, Scott M. Lephart, FACSM. University of Pittsburgh, Pittsburgh, PA., 101st Airborne Division (Air Assault), Fort Campbell, KY

To achieve optimal military readiness, Soldiers are turning to dietary supplements (DS) to increase strength, endurance, alertness and overall health. **PURPOSE:** Evaluate DS habits of 101<sup>st</sup> Airborne Division (Air Assault) Soldiers. **METHODS:** A total of 390 Soldiers completed a diet history including a detailed DS questionnaire. **RESULTS:** Sixty-one percent (n=236; Age  $29.0 \pm 6.6$  years; BMI  $26.7 \pm 3.4$  kg/m<sup>2</sup>) of Soldiers consume at least one DS, of these 58% consume multivitamin supplements (MV), 32% whey protein, 16% energy drinks, 10% creatine and 10% nitric oxide (Table 1). Fifty-one percent consume more than one DS.

Table 1: Dietary Supplement Use, Perceived Benefits and Adverse Reactions

Supplement	Purpose of Use	Usage	Perceived Benefit	Adverse Reaction
MV	Supplement diet & improve health  Improve performance  Improve joint health	Military Training (MT) 52% Deployed (DP) 24% Both 24%	More energy/less fatigue Fewer colds  Increase well being	Nausea
Whey	Increase muscle mass, strength, recovery  Improve performance  Supplement diet and improve health	MT 53% DP 25% Both 16%	Increase muscle mass  Recovery  Weight/body fat loss	Decrease appetite  Weight gain
Energy Drink	Improve physical performance  Improve cognitive function  Improve joint health	MT 37% DP 34% Both 29%	Feel more energized Alertness Stay awake	Jittery feeling Dehydration Indigestion Crashing feeling Dependency
Creatine	Increase muscle mass, strength, recovery.  Improve performance  Supplement diet and improve health	MT 50% DP 29% Both 17% N/A 4%	Increase work out duration/intensity  Increase muscle strength, size, endurance	Upset stomach Dehydration
Nitric Oxide	Increase muscle mass, strength, recovery.  Improve physical performance	MT 53% DP 18% Both 18% N/A 11%	Increase energy to workout  Less muscle soreness	None reported



	Supplement diet and improve health		Improve quality of workout	
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**CONCLUSION:** Soldiers are using DS to correct nutrient inadequacies and improve the quality of the daily diet, in order to optimize adaptations from training, expedite recovery and improve health and physical readiness. Future efforts should focus on educating Soldiers to use foods, fluids and nutrient timing as a safer and more effective alternative to DS.

Supported by the U.S. Army Medical Research and Materiel Command under Award No. W81XWH-06-2-0070/09-2-0095

## **Clinically Significant Side-to-Side Lower Extremity Strength Asymmetries in US Army 101st Airborne Soldiers**

Nicholas C. Clark, Karen A. Keenan, John P. Abt, Timothy C. Sell, Takashi Nagai, Jennifer B. Deluzio, Mita T. Lovalekar, Larry J. McCord, Michael D. Wirt, Scott M. Lephart FACSM. University of Pittsburgh, Pittsburgh, PA, 101st Airborne Division (Air Assault), Fort Campbell, KY

Side-to-side (S-S) symmetry of lower extremity (LE) muscle strength is important for preventing between-limb compensations that overload one side and increase injury risk. As such, S-S comparisons in LE strength are frequently made in injury prevention and rehabilitation contexts. Past work consistently shows S-S LE strength differences <10% are normal in athletes. However, S-S LE strength differences in large military samples have not been previously reported. Considering the healthcare burden of unintentional musculoskeletal injuries, characterizing the S-S LE strength differences in Soldiers will give data of the frequency of potentially dangerous S-S muscle imbalance. This data can then be used to screen for future risk of new LE injury or re-injury. **PURPOSE:** To describe the prevalence of clinically significant S-S asymmetry (S-S difference >10%) in LE strength of Soldiers. **METHODS:** Fully operational male US Army 101st Airborne Soldiers (n=402; age  $28.1 \pm 6.6$ yr; height  $177.7 \pm 7.1$ cm; mass  $84.1 \pm 12.5$ kg) were tested. An isokinetic dynamometer measured concentric quadriceps (QUAD) and hamstring (HAM) mean peak torque (Nm/kg, 5 reciprocal repetitions, 60°/sec), and isometric hip abductor (ABD) mean peak force (N/kg, 3 reciprocal repetitions, 5 sec/effort). A handheld dynamometer measured isometric ankle eversion (EV) and inversion (INV) mean peak force (kg, 3 repetitions, 5 secs/effort). Counts were made of Soldiers with S-S differences >10% (designated 'suprathreshold'(ST)) and proportions calculated. **RESULTS:** For QUAD and HAM strength, 41% had S-S differences >10% (ST range=11-50%). For ABD strength, 38% had S-S differences >10% (ST range=11-53%). For EV strength, 34% had S-S differences >10% (ST range=11-37.5%). For INV strength, 37% has S-S differences >10% (ST range=11-40%). **CONCLUSION:** A large proportion of Soldiers (>33%) had S-S leg strength differences >10% (maximum S-S difference=53%). Consideration should be given to correction of S-S imbalances via targeted training programs. Such intervention may contribute to reducing the risk of sustaining new unintentional LE injury or re-injury, and enhance Soldiers' ability to safely and effectively execute mission essential tasks.

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## Dietary Supplement Habits of Soldiers of 101<sup>st</sup> Airborne Division Air Assault

To achieve optimal military readiness, Soldiers are turning to dietary supplements (DS) to increase strength, endurance, alertness and overall health. **PURPOSE:** Evaluate DS habits of 101<sup>st</sup> Airborne Division (Air Assault) Soldiers. **METHODS:** A total of 390 Soldiers completed a diet history including a detailed DS questionnaire. **RESULTS:** Sixty-one percent (n=236; Age  $29.0 \pm 6.6$  years; BMI  $26.7 \pm 3.4$  kg/m<sup>2</sup>) of Soldiers consume at least one DS, of these 58% consume multivitamin supplements (MV), 32% whey protein, 16% energy drinks, 10% creatine and 10% nitric oxide (Table 1). Fifty-one percent consume more than one DS.

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Nitric Oxide	Increase muscle mass, strength, recovery.  Improve physical performance  Supplement diet and	MT 53% DP 18% Both 18% N/A 11%	Increase energy to workout  Less muscle soreness  Improve quality of	None reported

	improve health		workout	
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**CONCLUSION:** Soldiers are using DS to correct nutrient inadequacies and improve the quality of the daily diet, in order to optimize adaptations from training, expedite recovery and improve health and physical readiness. Future efforts should focus on educating Soldiers to use foods, fluids and nutrient timing as a safer and more effective alternative to DS.

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**Submitted on Feb. 2012 (currently under review) - Lovalekar M, Abt J, Sell T, Nagai T, Deluzio J, Wirt M, Lephart S. Measuring self-reported recall of unintentional musculoskeletal injuries in an Army Airborne Division. 140th Annual Meeting & Exposition of the American Public Health Association; October 27-31, 2012; San Francisco, CA.**

**Background/Purpose:** Self-reported data are often used in epidemiology, but self-reported recall of comprehensive injury data has not been measured among soldiers. The aim of this analysis was to assess self-reported recall of unintentional musculoskeletal injuries among soldiers in an Army Airborne Division.

**Methods:** Self-reported and medical chart-reviewed injuries among 115 soldiers (age  $26.6 \pm 5.8$  years (mean  $\pm$  SD), 87.0% male) were matched by anatomic location, side (for extremity injuries), year, and type. The injuries included in the analysis were those that had occurred during the year of survey (recent injuries), and during the preceding calendar year (old injuries). Recall was expressed as the percent of medical chart-reviewed injuries correctly recalled in the self-report. Proportions were compared using the Fisher's exact test.

**Results/Outcomes:** Eighty-seven injuries were recorded in the medical charts. Common injury types were pain/spasm/ache (29/87, 33.3% of the injuries), sprain (18/87, 20.7%), and strain (15/87, 17.2%). Overall, recall was low (9/87 = 10.3%). Recall was higher for severe injuries (traumatic/stress fractures, 1/4 = 25.0%) as compared to less severe injuries (non-fracture injuries, 8/83 = 9.6%), but the difference was not statistically significant ( $p = 0.359$ ). Recall was higher for recent injuries (3/26 = 11.5%) as compared to old injuries (6/61 = 9.8%), but the difference was not statistically significant ( $p = 1.000$ ).

**Conclusion:** The low self-reported recall in this study underscores the need for further investigation of factors affecting recall and strategies to improve accuracy of recall of injury data in various military populations.

**Submitted on Feb. 2011 and presented on Nov. 2011 - Lovalekar M, Abt J, Sell T, House A, Nagai T, Pederson J, Lephart S. Comparison of self-reported musculoskeletal injury history between female and male US Army Soldiers. 139th Annual Meeting & Exposition of the American Public Health Association; October 29 - November 2, 2011; Washington, DC.**

**Background/ Purpose:** Musculoskeletal injuries can adversely impact performance and certain injuries are risk factors for recurrence of the injury. The aim of this analysis was to compare the proportion of female and male US Army Soldiers with a self-reported history of musculoskeletal injury.

**Methods:** Self-reported musculoskeletal injury history for a period of two years was obtained from 296 Soldiers (age =  $27.8 \pm 6.5$  years, 12.2% female). Injuries were classified according to their anatomic location and injury type (traumatic vs. overuse). Proportions of subjects with injuries were compared using Fisher's exact test.

**Results:** Age was not significantly different between genders (females  $27.0 \pm 6.0$  years, males  $27.9 \pm 6.6$  years,  $p = 0.440$ ). A greater proportion of females reported a musculoskeletal injury compared to males (41.7% and 28.1% respectively,  $p = 0.119$ ), though this difference was not statistically significant. A greater proportion of females than males reported a lower extremity injury (27.8%, 13.8%,  $p = 0.046$ ) and a knee injury (11.1%, 2.7%,  $p = 0.033$ ). There was no difference in the proportion of females and males reporting an upper extremity injury (5.6%, 7.7%,  $p = 1.000$ ). Interestingly, a greater proportion of females than males reported an overuse injury (22.2%, 8.8%,  $p = 0.036$ ).

**Conclusions:** Examination of potential physiological, musculoskeletal, biomechanical and nutritional risk factors in these subjects is necessary. There may be a need to implement a customized program to prevent recurrence of certain lower extremity and overuse injuries in female Soldiers, and to prevent an adverse impact on performance.

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# TITLE PAGE

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## The Addition of Body Armor Diminishes Dynamic Postural Stability in Military Soldiers

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**KEYWORDS**

Postural Stability, Load Carriage, Body Amor, Jump Landing



## **ABSTRACT**

Poor postural stability has been identified as a risk factor for lower extremity musculoskeletal injury. The additional weight of body armor carried by Soldiers alters static postural stability and may predispose Soldiers to lower extremity musculoskeletal injuries. However, static postural stability tasks poorly replicate the dynamic military environment which places considerable stress on the postural control system during tactical training and combat. Therefore, the purpose of this study was to examine the effects of personal body armor on dynamic postural stability during single-leg jump landings. Thirty-six 101st Airborne Division (Air Assault) Soldiers performed single-leg jump landings in the anterior direction with and without wearing personal body armor. The dynamic postural stability index (DPSI) was calculated for each condition. The addition of personal body armor resulted in diminished dynamic postural stability. Altered dynamic postural stability may result in increased lower extremity injuries. It is recommended that postural stability training be incorporated into physical training as well as the incorporation of body armor into physical training in order to promote adaptations that will result in safer performance during dynamic tasks while wearing body armor.

## INTRODUCTION

Postural stability has been defined by Riemann et al<sup>1</sup> as the process of coordinating corrective movement strategies and movements at the selected joints to remain in postural equilibrium.

Dynamic postural stability is the ability to maintain the base of support when the base of support is moving or when an external perturbation is applied to the body.<sup>2</sup> Postural stability has been identified as a risk factor for ankle<sup>3-9</sup> and knee<sup>10, 11</sup> injuries in athletic populations and is likely a risk factor for injury in the military. Soldiers are often required to carry heavy loads while deployed and on tactical operations for long distances and over rugged terrains.<sup>12, 13</sup> The loads Soldiers carry are determined by the mission requirements and for protective purposes with the minimum load consisting of body armor which accounts for 31% of a Soldiers fighting load.<sup>14</sup> The effects of load carriage on physiological function<sup>15-17</sup> and gait<sup>18, 19</sup> have been established. However, the effect of load carriage on postural stability<sup>20, 21</sup> is largely unknown and has only incorporated static testing conditions. Static testing conditions fail to replicate the dynamic military environment,<sup>22</sup> which places significant demands on postural control encountered during tactical training and missions.

Ankle and knee injuries<sup>23-25</sup> are a common occurrence in military personnel and are associated with high medical costs,<sup>26</sup> lost time from duty,<sup>24</sup> and impact military readiness.<sup>24</sup> Ankle and knee injuries account for 10.9%<sup>23</sup> to 15.1%<sup>25</sup> and 10.2%<sup>23</sup> to 12.0%,<sup>25</sup> respectively, of all musculoskeletal injuries in military personnel. Additionally, the lower extremity is the most common anatomical location of hospitalized injuries in the military.<sup>27</sup> Furthermore, ankle and knee injuries were among the most common anatomical locations for non-battle air evacuations during Operations Iraqi Freedom and Enduring Freedom.<sup>28</sup> Despite the frequent occurrence of

ankle and knee injuries in the military the risk factors for these injuries are largely unknown in this population.

Decreased postural stability has been prospectively identified as a risk factor for ankle<sup>4, 7-9</sup> and leg<sup>11</sup> injuries. Altered postural stability has also been observed following knee,<sup>10, 11</sup> and low back<sup>29, 30</sup> injuries. The effects of load carriage on postural stability<sup>20, 21</sup> in Soldiers is limited and has only assessed static testing conditions which fail to imitate military activities. Schiffman and colleagues<sup>21</sup> assessed the effects of three different loads (6, 16, and 40 kg) on static postural stability and observed linear increases in COP excursions with increases in load. Moreover, May et al.<sup>20</sup> demonstrated decreased balance scores while carrying a load equal to 30% of body weight during the modified sensory organizational test (SOT). While the effect of load carriage appears to be detrimental to static postural stability its effect on dynamic postural stability is largely unknown and warrants investigation.

A direct connection between load carriage and risk of injury has not been established but recent epidemiological evidence indicates that the Soldier does perceive it to be a risk factor for injury.<sup>31</sup> Additionally, recent epidemiological evidence demonstrates an increase in ankle and knee injuries in Afghanistan compared to Iraq.<sup>28</sup> The reported increase is likely due to the challenging terrain that is difficult to traverse under normal conditions and even more demanding while carrying the load necessary for tactical missions. It is suggested that load carriage over long durations may result in injury, especially to the ankle and knee.<sup>32</sup> The most common self-reported region being uncomfortable during loaded field marching were the foot and ankle.<sup>33</sup> Additionally, it was documented that 24% of infantry Soldiers who participated in loaded road marching suffered an overuse injury.<sup>34</sup> The addition of carrying an unaccustomed load while

deployed is suggested to increase ankle and knee injuries which may be because of the detrimental effects load carriage has on postural stability.

Altered or diminished postural stability has been demonstrated to be a risk factor for lower leg<sup>3-11</sup> injuries. Military personnel carry and wear additional weight for tactical and protective purposes. This additional weight likely has impact on dynamic postural stability. The degree of this altered postural stability is unknown. The overall purpose of this study was to examine the effects of personal body armor on dynamic postural stability as measured by the dynamic postural stability index (DPSI). We hypothesized that the addition of body armor would significantly decrease the Soldier's dynamic postural stability as indicated by an increase in the DPSI. If our hypothesis is correct, the results of this study will provide evidence for the need for postural stability training that incorporates load carriage prior to deployment or prior to tactical training.

## **METHODS**

### **Participants**

Thirty-six subjects (male = 32, female = 4) were recruited from the Army 101st Airborne Division (Air Assault) to participate in this study (Table 1). To participate, subjects must have been 18 to 45 years old from the 101st, with no history of concussion or mild head injury in the previous year, no upper extremity, lower extremity, or back musculoskeletal pathology in the past three months that could affect the ability to perform the required tests, and no history of neurologic or balance disorders. Additionally, all subjects were cleared for active duty without any recent prescribed duty restrictions. Approval for this study was obtained from the University of Pittsburgh's Institutional Review Board, Eisenhower Army Medical Center, Clinical Investigation Regulatory Office, and the Human Research Protection Office as part of an

ongoing research project focusing on injury prevention and performance optimization in the 101st Airborne Division (Air Assault). All testing was conducted at our Human Performance Research Laboratory, Fort Campbell, KY, a remote research facility operated by the Neuromuscular Research Laboratory, University of Pittsburgh.

### **Instrumentation**

A force plate (Kistler 9286A, Amherst, NY) was used to collect the ground reaction force data (1200 Hz) during the single-leg jump landing task to assess dynamic postural stability. Force plate data were passed through an amplifier and analog to digital board (DT3010, Digital Translation, Marlboro, MA) and stored on a personal computer.

### **Load Carriage Condition**

The load carriage condition was comprised of standard US Army clothing (boots, socks, T-shirt, and shorts) and equipment (body armor). Each subject wore their own personal body armor, the average weight of the body armor and the body armor as percentage of body weight can be found in Table 1. The body armor was chosen as it is the minimum load Soldiers carry while on missions and during tactical training.

### **Procedures**

Subjects reported to a research laboratory for a single test session. Dynamic postural stability was assessed using a single-leg jump landing in the anterior direction which has demonstrated good intersession reliability, 0.86.<sup>22</sup> The single-leg jump landing task was only conducted on the dominant limb. Limb dominance was defined as the limb the subject would use to kick a ball maximally. The jump distance was normalized to the subject's body height and the jump height was standardized at 30cm.<sup>22</sup> Subjects were positioned 40% of their body height away from the edge of a force plate and a 30cm hurdle was placed at the midpoint between the starting position

and the force plate. Subjects were instructed to jump in the anterior direction using a two-footed jump over the hurdle and to land on the force plate with only the dominant leg, stabilize as quickly as possible, place their hands on their hips once stabilized, and remain still for 10 seconds while looking forward. Upper extremity movement was unrestricted during the jump, however, once subjects were stabilized they were asked to quickly place their hands on their hips. Subjects were allowed three practice trials to become familiar with the single-leg jump landing task. A one minute rest period was provided between trials to prevent fatigue.

Trials were discarded and repeated if subjects failed to jump over or came in contact with the hurdle; or if the non-dominant leg came in contact with the dominant leg or the ground around the force plate. All of the subjects performed the task without body armor first. A total of three successful trials were collected and used for data analysis.

### **Data Reduction**

A custom MATLAB (v7.0.4, Natick, MA) script file was used to process the ground reaction force data for calculating the dynamic postural stability index (DPSI). Ground reaction force data were passed through a zero-lag 4<sup>th</sup> order low pass Butterworth filter with a frequency cutoff of 20 Hz. The dependent variable was the DPSI depicted in Figure 1. The DPSI is a composite of the anterior-posterior, medial-lateral and vertical ground reaction forces and also provides stability indices for the anterior-posterior (APSI), medial-lateral (MLSI) and vertical (VSI) directions. The DPSI was calculated using the first three seconds of the ground reaction forces immediately following initial contact identified as the instant the vertical ground reaction force exceeded 5% body weight. This method of calculating DPSI has demonstrated good reliability, 0.96.<sup>35</sup> Higher stability indices and DPSI scores represent worse dynamic postural stability. Each subject had a total of three trials which were averaged and used for final analysis.

## **Statistical Analysis**

Paired sample t-tests were performed for the dependent variables to determine if there was a significant difference between no load carriage and load carriage conditions. All statistical analyses were compared using SPSS (v13.0, SPSS Inc., Chicago, IL). An alpha level of 0.05 was set *a priori* to determine significance for all statistical analyses.

## **RESULTS**

The means, standard deviations, and results of the paired sample t-tests for all variables are presented in Table 2. Overall, the subjects performed the dynamic postural stability test significantly different between the load and no-load conditions. Specifically, under the load condition, the subjects had significantly worse scores for the MLSI, APSI, VSI and DPSI.

## **DISCUSSION**

Decreased postural stability has been identified as a risk factor for ankle<sup>3-9</sup> and knee<sup>10, 11</sup> injuries in athletic populations. The equipment Soldiers carry for personal protection and tactical purposes places considerable weight on the Soldiers' bodies, with the minimal load consisting of body armor. Load carriage negatively affects physiological function,<sup>15-17</sup> gait,<sup>18, 19</sup> and static postural stability<sup>20, 21</sup>; however, its effect on dynamic postural stability has yet to be explored. The purpose of this study was to investigate the influence of body armor on dynamic postural stability. The results of this study indicate that the addition of body armor diminishes dynamic postural stability. Specifically, increases were noted in the MLSI, APSI, VSI and DPSI confirming our hypothesis. It is suggested that postural stability training be implemented as well as physical training that incorporates the addition of body armor or additional load to induce adaptations that will likely mitigate the negative effects of body armor on dynamic postural stability.

The addition of body armor reduced dynamic postural stability. Ground reaction forces have consistently been shown to increase with the addition of a load<sup>18, 19, 36</sup> which was evidenced by higher MLSI, APSI, and VSI scores in the current study. Similarly, peak vertical ground reaction forces significantly increased during two-legged drop landings with the addition of body armor, helmet and rifle.<sup>37</sup> Additionally, carrying a load results in an increase in body sway<sup>21, 36</sup> resulting in less stability which may explain the increase in ground reaction forces observed in this study. Furthermore, it has been established that carrying a load results in a forward lean<sup>38</sup> thereby, placing a subject closer to their limits of stability which may result in an increase in ground reaction forces.

Poor postural stability has been prospectively identified as a risk factor for ankle<sup>4, 7-9</sup> and leg<sup>11</sup> injuries. In the current study, the addition of body armor resulted in Soldiers landing with greater ground reaction forces in the anterior-posterior, medial-lateral and vertical directions. Landing with greater peak vertical ground reaction forces has been identified as a risk factor for ACL injury.<sup>39</sup> A 10% increase was observed with the addition of body armor for the MLSI and APSI scores, whereas a 7% increase was observed for the VSI and DPSI scores. Increases in the MLSI may have important considerations for lateral ankle sprains as they occur in the frontal plane<sup>40</sup> and individuals with chronic ankle instability have increased MLSI scores compared to healthy controls.<sup>41</sup> The relationship between load carriage and injury rates has yet to be established, however, preliminary data suggests load carriage results in an increase in musculoskeletal injuries.<sup>31</sup> The potential cause for an increase in musculoskeletal injuries may be due to diminished dynamic postural stability while carrying a load. The load utilized in this study was the minimum load a Soldier would carry. As loads approach those of tactical operations decrements in dynamic postural stability are likely to increase.



A variety of postural stability training programs have been developed. These programs have demonstrated the ability to improve postural stability and reduce musculoskeletal injuries.<sup>42</sup> Currently, postural stability training is not incorporated into daily Army physical training; however, it is included in newer military training programs.<sup>43</sup> The Eagle Tactical Athlete Program (ETAP) has been implemented at the 101st Airborne Division (Air Assault). This program is an eight week periodized training regimen that incorporates postural stability and physical training while wearing body armor that improved Soldier's postural stability. Additionally, proper landing technique should be emphasized to reduce the effects of body armor on dynamic postural stability. Proper landing technique programs have been successfully developed to reduce ACL injury in female athletes.<sup>44</sup> Our previous research has demonstrated that hip flexion and extension angles at initial contact are important predictors of DPSI.<sup>45</sup> Specifically, greater hip flexion and extension angles resulted in lower DPSI scores indicating better dynamic postural stability. Additionally, greater knee flexion at initial contact as well as greater knee flexion throughout the landing results in a greater dissipation of ground reaction forces.<sup>46</sup> Furthermore, earlier onset of muscle activation improves reaction to the landing surface and reduces the time to transition from a dynamic to a static state resulting in a successful jump landing.<sup>47</sup>

In the current study, the average weight of the body armor was 12.5 kg which was approximately 15.5% of subjects' body mass. This load was selected as it is the minimum amount of equipment Soldiers wear for protective purposes. It has been established that load carriage considerably alters physiological function,<sup>15-17</sup> gait,<sup>18, 19</sup> static postural stability,<sup>20, 21</sup> knee kinematics during drop landings,<sup>37</sup> and potentially contributes to musculoskeletal injuries.<sup>31</sup> Carrying additional weight has been part of Army physical training, but has traditionally been

limited to field marches. However, during deployment Soldiers may be required to carry loads in excess of 100 pounds.<sup>14</sup> The integration of additional weight into physical and tactical training as well as the incorporation of postural stability training is encouraged in order to mitigate the effects of additional weight on dynamic postural stability potentially decreasing lower extremity musculoskeletal injuries.

We acknowledge that this study has several limitations. First, the weight of the body armor varied between subjects as each subject wore their own personal body armor. The weight of body armor can vary between individual Soldiers based on their needs and preferences. Additionally, Soldiers are accustomed with their own body armor weight. Incorporating a standardized body armor weight could have potentially negatively affected Soldier performance during the dynamic postural stability tasks as Soldiers may not have been accustomed to the body armor weight. The influence of different body armor weights would likely have the greatest effect on the VSI which is most susceptible to variations in weight. Second, the order of the two testing conditions was not randomized. It is possible that a learning effect could have influenced the dynamic postural stability measures during the Load condition because it followed the No-Load condition. In an attempt to mitigate this effect, a minimum of three practice trials were provided for each condition. More practice trials were allowed, as needed, until subjects felt comfortable with the test procedures. Since subjects were provided time to become familiarized with the single-leg jump landing task during both conditions, it is unlikely that the order of the two testing conditions would provide further alteration of performance.

Future research should explore the influence of carrying additional weight on injury rates in the military during deployment and non-deployment. Additionally, future research should examine the effects of carrying additional weight during other dynamic postural stability tasks

that replicate the military environment as well as incorporating various loads that are reflective of the loads Soldiers carry during combat and tactical missions. Furthermore, a prospective study is needed in order to demonstrate that dynamic postural stability is a risk factor for lower extremity injuries in the military.

## **CONCLUSION**

The addition of a minimum load such as body armor results in diminished dynamic postural stability as evidenced by increases in MLSI, APSI, VSI and DPSI. Altered dynamic postural stability may result in an increase in lower extremity musculoskeletal injuries. Due to the deleterious effects body armor has on dynamic postural stability, it is suggested that postural stability training be incorporated into daily Army physical training. Load carriage should be integrated into physical training to promote adaptations that will result in safer performance during load-bearing dynamic tasks.

## **ACKNOWLEDEMENTS**

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Table 1. Subject Demographics and Body Armor Weight

Characteristic	Mean		SD
Age (yr)	29	±	6.6
Height (cm)	174.49	±	8.84
Weight (kg)	82.38	±	13.93
Body Armor (kg)	12.47	±	2.56
Body Armor Percent of Body Weight (%)	15.55	±	4.18

Table 2. Dynamic Postural Stability During No-Load and Load Conditions

Variable	Condition						<i>p</i> value
	No-Load			Load			
MLSI	0.025	±	0.006	0.028	±	0.006	0.005
APSI	0.119	±	0.011	0.132	±	0.012	<0.001
VSI	0.229	±	0.042	0.319	±	0.047	<0.001
DPSI	0.324	±	0.041	0.347	±	0.045	<0.001

Statistical significance set at  $p < 0.05$

MLSI = medial lateral stability index

APSI = anterior posterior stability index

VSI = vertical stability index

DPSI = composite score

Figure 1. DPSI Calculation

$$DPSI = \left( \sqrt{\frac{\sum(0 - GRFx)^2 + \sum(0 - GRFy)^2 + \sum(body\ weight - GRFz)^2}{number\ of\ data\ points}} \right) \div body\ weight$$

## References

1. Riemann BL, Guskiewicz KM, and Shields EW: Relationship Between Clinical and Forceplate Measures of Postural Stability. *J Sport Rehabil*, 1999. 8(2): p. 71-82.
2. Brown CN and Mynark R: Balance deficits in recreational athletes with chronic ankle instability. *J Athl Train*, 2007. 42(3): p. 367-73.
3. Hertel J and Olmsted-Kramer LC: Deficits in time-to-boundary measures of postural control with chronic ankle instability. *Gait Posture*, 2007. 25(1): p. 33-9.
4. McGuine TA, Greene JJ, Best T, and Levenson G: Balance as a predictor of ankle injuries in high school basketball players. *Clin J Sport Med*, 2000. 10(4): p. 239-244.
5. McKeon PO and Hertel J: Spatiotemporal postural control deficits are present in those with chronic ankle instability. *BMC Musculoskelet Disord*, 2008. 9: p. 76.
6. Ross SE, Guskiewicz KM, Gross MT, and Yu B: Balance measures for discriminating between functionally unstable and stable ankles. *Med Sci Sports Exerc*, 2009. 41(2): p. 399-407.
7. Trojan TH and McKeag DB: Single leg balance test to identify risk of ankle sprains. *Br J Sports Med*, 2006. 40(7): p. 610-3; discussion 613.
8. Wang HK, Chen CH, Shiang TY, Jan MH, and Lin KH: Risk-factor analysis of high school basketball-player ankle injuries: a prospective controlled cohort study evaluating postural sway, ankle strength, and flexibility. *Arch Phys Med Rehabil*, 2006. 87(6): p. 821-5.
9. Willems TM, Witvrouw E, Delbaere K, Mahieu N, De Bourdeaudhuij I, and De Clercq D: Intrinsic risk factors for inversion ankle sprains in male subjects: a prospective study. *Am J Sports Med*, 2005. 33(3): p. 415-23.
10. Alonso AC, Greve JM, and Camanho GL: Evaluating the center of gravity of dislocations in soccer players with and without reconstruction of the anterior cruciate ligament using a balance platform. *Clinics (Sao Paulo)*, 2009. 64(3): p. 163-70.
11. Soderman K, Alfredson H, Pietila T, and Werner S: Risk factors for leg injuries in female soccer players: a prospective investigation during one out-door season. *Knee Surg Sports Traumatol Arthrosc*, 2001. 9(5): p. 313-21.
12. Knapik J, Harman E, and Reynolds K: Load carriage using packs: a review of physiological, biomechanical and medical aspects. *Appl Ergon*, 1996. 27(3): p. 207-16.
13. Knapik JJ, Reynolds KL, and Harman E: Soldier load carriage: historical, physiological, biomechanical, and medical aspects. *Mil Med*, 2004. 169(1): p. 45-56.
14. Task Force Devil Combined Arms Assessment Team (2003). The modern warrior's combat load: Dismounted operations in Afghanistan (Draft 8-14-2003). Fort Leavenworth, KS: U.S. Army Center for Army Lessons Learned.
15. Beekley MD, Alt J, Buckley CM, Duffey M, and Crowder TA: Effects of heavy load carriage during constant-speed, simulated, road marching. *Mil Med*, 2007. 172(6): p. 592-5.
16. Lloyd R and Cooke CB: The oxygen consumption associated with unloaded walking and load carriage using two different backpack designs. *Eur J Appl Physiol*, 2000. 81(6): p. 486-92.
17. Quesada PM, Mengelkoch LJ, Hale RC, and Simon SR: Biomechanical and metabolic effects of varying backpack loading on simulated marching. *Ergonomics*, 2000. 43(3): p. 293-309.

18. Lloyd R and Cooke CB: Kinetic changes associated with load carriage using two rucksack designs. *Ergonomics*, 2000. 43(9): p. 1331-41.
19. Tilbury-Davis DC and Hooper RH: The kinetic and kinematic effects of increasing load carriage upon the lower limb. *Hum Mov Sci*, 1999. 18: p. 693-700.
20. May B, Tomporowski PD, and Ferrara M: Effects of backpack load on balance and decisional processes. *Mil Med*, 2009. 174(12): p. 1308-12.
21. Schiffman JM, Bensek CK, Hasselquist L, Gregorczyk KN, and Piscitelle L: Effects of carried weight on random motion and traditional measures of postural sway. *Appl Ergon*, 2006. 37(5): p. 607-14.
22. Sell TC, House AJ, Huang HC, Abt JP, and Lephart SM: An Examination, Correlation, and Comparison of Static and Dynamic Measures of Postural Stability in Healthy, Physically Active Adults. *Phys Ther Sport* (In Press), 2011.
23. Jones BH, Cowan DN, Tomlinson JP, Robinson JR, Polly DW, and Frykman PN: Epidemiology of injuries associated with physical training among young men in the army. *Med Sci Sports Exerc*, 1993. 25(2): p. 197-203.
24. Lauder TD, Baker SP, Smith GS, and Lincoln AE: Sports and physical training injury hospitalizations in the army. *Am J Prev Med*, 2000. 18(3 Suppl): p. 118-28.
25. Strowbridge NF and Burgess KR: Sports and training injuries in British soldiers: the Colchester Garrison Sports Injury and Rehabilitation Centre. *J R Army Med Corps*, 2002. 148(3): p. 236-43.
26. Soboroff SH, Pappius EM, and Komaroff AL: Benefits, risks, and costs of alternative approaches to the evaluation and treatment of severe ankle sprain. *Clin Orthop Relat Res*, 1984(183): p. 160-8.
27. Jones BH, Canham-Chervak M, Canada S, Mitchener TA, and Moore S: Medical surveillance of injuries in the u.s. Military descriptive epidemiology and recommendations for improvement. *Am J Prev Med*, 2010. 38(1 Suppl): p. S42-60.
28. Hauret KG, Taylor BJ, Clemmons NS, Block SR, and Jones BH: Frequency and Causes of Nonbattle Injuries Air Evacuated from Operations Iraqi Freedom and Enduring Freedom, U.S. Army, 2001-2006. *Am J Prev Med*, 2010. 38(1 Suppl): p. S94-107.
29. Brumagne S, Janssens L, Knapen S, Claeys K, and Suuden-Johanson E: Persons with recurrent low back pain exhibit a rigid postural control strategy. *Eur Spine J*, 2008. 17(9): p. 1177-84.
30. Alexander KM and LaPier TL: Differences in static balance and weight distribution between normal subjects and subjects with chronic unilateral low back pain. *J Orthop Sports Phys Ther*, 1998. 28(6): p. 378-83.
31. Sell TC, Lovalekar MT, Nagai T, House AJ, Smalley BW, Abt JP, and Lephart SM: The Perception of Load Carriage as a Risk Factor for Injury in U.S. Army Soldiers. Presented at: 58th ACSM Annual Meeting and World Congress on Exercise is Medicine; May 31-June 4, 2011; Denver, CO.
32. Birrell SA and Hooper RH: Initial subjective load carriage injury data collected with interviews and questionnaires. *Mil Med*, 2007. 172(3): p. 306-11.
33. Birrell SA and Haslam RA: Subjective skeletal discomfort measured using a comfort questionnaire following a load carriage exercise. *Mil Med*, 2009. 174(2): p. 177-82.



34. Knapik J, Reynolds K, Staab J, Vogel JA, and Jones B: Injuries associated with strenuous road marching. *Mil Med*, 1992. 157(2): p. 64-7.
35. Wikstrom EA, Tillman MD, Smith AN, and Borsa PA: A new force-plate technology measure of dynamic postural stability: the dynamic postural stability index. *J Athl Train*, 2005. 40(4): p. 305-9.
36. Birrell SA, Hooper RH, and Haslam RA: The effect of military load carriage on ground reaction forces. *Gait Posture*, 2007. 26(4): p. 611-4.
37. Sell TC, Chu Y, Abt JP, Nagai T, Deluzio J, McGrail MA, Rowe RS, and Lephart SM: Minimal Additional Weight of Combat Equipment Alters Air Assault Soldiers' Landing Biomechanics. *Mil Med*, 2010. 175(1): p. 41.
38. Attwells RL, Birrell SA, Hooper RH, and Mansfield NJ: Influence of carrying heavy loads on soldiers' posture, movements and gait. *Ergonomics*, 2006. 49(14): p. 1527-37.
39. Hewett TE, Myer GD, Ford KR, Heidt RS, Jr., Colosimo AJ, McLean SG, van den Bogert AJ, Paterno MV, and Succop P: Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med*, 2005. 33(4): p. 492-501.
40. Hertel J: Functional Anatomy, Pathomechanics, and Pathophysiology of Lateral Ankle Instability. *J Athl Train*, 2002. 37(4): p. 364-375.
41. Wikstrom EA, Tillman MD, Chmielewski TL, Cauraugh JH, Naugle KE, and Borsa PA: Dynamic postural control but not mechanical stability differs among those with and without chronic ankle instability. *Scand J Med Sci Sports*, 2009. 20(1): p. e137-44.
42. Hubscher M, Zech A, Pfeifer K, Hansel F, Vogt L, and Banzer W: Neuromuscular training for sports injury prevention: a systematic review. *Med Sci Sports Exerc*, 2010. 42(3): p. 413-21.
43. Abt JP, Sell TC, Lovalekar M, Crawford K, Nagai T, Deluzio JB, Smalley BW, McGrail MA, Rowe RS, and Lephart SM: Warrior Model for Injury Prevention and Human Performance - Eagle Tactical Athlete Program (ETAP) Part 2. *Journal Special Operations Medicine*, 2010. 10(4): p. 22-33.
44. Mandelbaum BR, Silvers HJ, Watanabe DS, Knarr JF, Thomas SD, Griffin LY, Kirkendall DT, and Garrett W, Jr.: Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2-year follow-up. *Am J Sports Med*, 2005. 33(7): p. 1003-10.
45. House AJ, Nagai T, Deluzio JB, Sell TC, Abt JP, Lovalekar MT, Smalley BW, and Lephart SM: Landing impact, hip kinematics, and hip strength predict dynamic postural stability in Army 101st airborne. Presented at: 57th ACSM Annual Meeting and World Congress on Exercise Is Medicine; June 2, 2010; Baltimore, MD.
46. Zhang SN, Bates BT, and Dufek JS: Contributions of lower extremity joints to energy dissipation during landings. *Med Sci Sports Exerc*, 2000. 32(4): p. 812-9.
47. Wikstrom EA, Tillman MD, Schenker S, and Borsa PA: Failed jump landing trials: deficits in neuromuscular control. *Scand J Med Sci Sports*, 2008. 18(1): p. 55-61.

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**Air-Assault Soldiers Demonstrate More Dangerous Landing Biomechanics When Visual  
Input Is Removed**

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KEYWORDS

Drop Landing, Non-contact Knee Injury, Visual Input, Injury Prevention

# Air-Assault Soldiers Demonstrate More Dangerous Landing Biomechanics When Visual Input Is Removed

## Introduction

Landing is a task widely performed in Soldiers’ physical and tactical training as well as tactical operations. Examples include exiting a vehicle (from a height), traversing a ditch, and climbing over an obstacle. Landing, even from low heights, typically induces high ground reaction forces, which are transferred-up of the kinetic chain of the lower extremities<sup>1</sup> and have been linked to musculoskeletal injuries in the lower body.<sup>2</sup> Non-contact knee injuries have been one of the most popular areas of research in sports medicine. Numerous studies have attempted to identify risk factors and biomechanical characteristics of such injuries.<sup>2-8</sup> The knee has been reported as the most frequently injured body part and accounted for 10 – 34% of all musculoskeletal injuries among different military groups, from Army Infantry to Naval Special Warfare trainees.<sup>9</sup> The frequency of ankle injury in military may be comparable or only secondary to the knee with 11 – 24% of all musculoskeletal injuries occurred at the ankle.<sup>9</sup> Lephart et al. suspected that ankle kinematics may have effects on the ground reaction forces during landing.<sup>5</sup> In simulated parachute landing, subjects who landed flat-footed demonstrated greater ground reaction forces than those who landed with the ball of the foot at initial ground contact.<sup>10</sup>

Soldiers can be viewed as tactical athletes. Unlike typical civilian athletes, Soldiers commonly perform their tasks with heavy equipment in challenging environments. Soldiers may need to perform tactical operations at nighttime for stealth and security purposes. While darkness makes a Soldier harder to be detected by enemies, it also decreases or deprives their use of visual

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4 input when interacting with the environment. Even with facilitating equipment such as night  
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6 vision goggles, the Soldier's visual input is still limited as compared to daytime. With limited  
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8 vision, the vestibular system and the somatosensory system must assume greater demands to  
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10 maintain Soldier's postural stability. It is questionable whether sufficient adaptations on these  
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12 two systems have been induced via the Soldier's physical and tactical training.  
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17 In the military, most research examining the effect of night operation on injuries have  
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19 focused on parachuting, during which 61 - 84% of injuries occurred at the moment of landing.<sup>11</sup>,  
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22 <sup>12</sup> The relative risk of injury was reported between 1.94 to 3.13 at night, compared with daytime  
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24 parachuting.<sup>11, 13</sup> According to a review by Knapik et al., similar elevated risks of injury during  
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26 night parachuting existed in airborne Soldiers of other countries: 2.4 in Israel, 4.1 in Belgium,  
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28 and between 1.3 to 41.2 in UK.<sup>14</sup> It is believed that limited visibility of the landing surface and  
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30 perception of distance and depth contributed to the higher risk of injury.<sup>14</sup> Such mechanisms  
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32 should apply to any general landing task with impaired vision. Some researchers have evaluated  
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34 the landing biomechanics with the removal of visual input with inconclusive results.<sup>15-18</sup> Santello  
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36 et al. found decreased maximum knee flexion and increased vertical ground reaction force  
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38 (VGRF) without vision,<sup>16</sup> while Liebermann and Goodman found unchanged or decreased  
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40 VGRF when blindfolded.<sup>15, 18</sup> Nevertheless, none of these studies involved military population.  
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42 Unlike the general population, Soldiers have been trained for night operation; such training may  
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44 induce certain adaptations. By observing Soldiers' night training in a qualitative task-analysis,  
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46 we determined that landing from a jump under low light conditions may be associated with  
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48 increased risk of lower extremity injury.<sup>19</sup> It is unclear how the biomechanical variables change  
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50 quantitatively in Soldiers when landing without vision and whether these potential changes  
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52 would suggest increased risk of lower body injury.  
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Therefore, the purpose of this study was to investigate how the removal of visual input would affect the lower body kinematics and kinetics of Soldiers performing a landing task. We hypothesized that the removal of visual input would alter landing mechanics and increase ground reaction forces.

## Methods

### Subjects

A total of 139 male 101st Airborne Division (Air Assault) Soldiers (Age:  $28.5 \pm 7.1$  years, Body Height:  $1.77 \pm 0.08$  m, Body Mass:  $83.3 \pm 13.5$  kg) voluntarily participated in this study. Eligible subjects were 18-55 year-old males cleared for participation in daily physical and training activities. Exclusion criteria included history of concussion or mild head injury in the previous year, lower extremity or back musculoskeletal pathology that could affect the ability to perform the tests within this study in the past three months, history of lower extremity musculoskeletal surgery, or history of neurological or balance disorders. Informed consent was obtained prior to performance of any testing procedures. The current study was approved by University's Institutional Review Board, Eisenhower Army Medical Center, Army Clinical Investigation Regulatory Office, and Army Human Research Protection Office. All the tests were conducted at our Research Center for Injury Prevention and Human Performance, Fort Campbell, KY.

### Instrumentation

Six high-speed cameras (Vicon, Centennial, CO) operating at 200 Hz and two force plates (Kistler Corporation, Amherst, NY) operating at 1200 Hz were used to capture the

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4 kinematic and ground reaction force data, respectively. The equipment was synchronized using  
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kinematic and ground reaction force data, respectively. The equipment was synchronized using  
Vicon Nexus software (Vicon, Centennial, CO).

## **Procedures**

Sixteen reflective markers were placed on subject's anatomical landmarks, including the  
ASISs, PSISs, lateral thighs, lateral knees, lateral shanks, lateral malleoli, calcanei, and 2<sup>nd</sup>  
metatarsals. Subjects' anthropometric parameters were measured using an anthropometer  
(Lafayette Instrument Company, Lafayette, IN). A static trial was captured for each subject at the  
anatomical position and served as the baseline for joint angle calculations.

The subjects were then asked to perform two-legged drop landings from a 50 cm platform  
under two conditions: with visual input (WV) and no visual input (NV). For the NV condition,  
visual input was removed by using a blindfold (Figure 1 and 2). In true training or combat  
environments Soldiers may drop from higher heights such as the deck of an HMMV (84cm) or an UH-  
60 Black Hawk Helicopter (115cm). In our pilot study, raising the platform height from 50cm to 100cm  
resulted in an increased VGRF of 95.5%BW. Because of safety concerns related to the large increase in  
VGRF, the 50cm platform height was chosen as this height is comparable to the median platform heights  
used in previous studies investigating the effects of vision removal.<sup>15-18</sup> The subjects were instructed to  
stand near the edge of the platform, drop off, land on both feet on the two force plates, and  
remain standing for two seconds after landing. The subjects were given at least three practice  
trials for each condition. Trials in which the subjects failed to regain balance or touched the  
ground off the force plates were rejected and replaced. Three successful trials were collected for  
each condition.

## **Data Reduction**

Vicon Nexus software was used to reconstruct 3D trajectories of the reflective markers. The trajectories were further smoothed with a general cross validation Woltring filter.<sup>20</sup> The trajectories of the hip, knee, ankle joint centers were estimated based on the marker locations and anthropometric parameters, according to Vicon's Plug-in Gait model (Vicon, Centennial, CO). The accuracy and validity of the model has been established.<sup>21-23</sup> The initial contact of each foot during landing was defined as the first sample during which vertical ground reaction forces exceeded 5% of the subject's body weight. The dependent variables included bilateral hip flexion, hip abduction, knee flexion, knee varus, and ankle flexion at initial contact and maximum values for hip flexion, knee flexion, ankle flexion, and vertical ground reaction forces (VGRF), and the time elapsed from initial contact to these maximum values.

## **Statistical Analysis**

Statistical analyses were performed using SPSS software (version 15, SPSS Inc., Chicago, IL). For each condition, dependent t-tests were applied to detect both bilateral difference and between-condition differences for each variable. Statistical significance was set at  $p < 0.05$ .

## **Results**

Results are presented in Table 1. Between-condition differences were detected in six variables. Under the NV condition, increased hip abduction angle and increased knee flexion angle at initial contact, decreased maximum knee flexion angle, greater maximum vertical ground reaction force, decreased time to maximum ankle dorsiflexion, and prolonged time to maximum vertical ground reaction force were detected in one or both legs.



Four variables showed significant bilateral differences. Hip flexion at initial contact, maximum knee flexion, and maximum vertical ground reaction force were different bilaterally in both conditions, while time to maximum ankle dorsiflexion was different bilaterally only under the NV condition.

## Discussion

Landing is a common task performed during military training and tactical operations such as exiting a vehicle from height, and traversing uneven terrain, or obstacles. When necessary, such tasks are performed at night reducing or eliminating visual input.<sup>19</sup> Affected visual input was considered the main reason of increased risk of injury during night parachuting,<sup>14</sup> and the same mechanism should apply to any general landing task under a condition of limited vision. The purpose of this study was to investigate how the removal of visual input would affect the lower body kinematics and kinetics of Soldiers performing a landing task using the biomechanical model developed previously.<sup>5-8</sup> The Soldiers in the current study landed with greater bilateral hip abduction angles at initial contact and lower bilateral maximum knee flexion angles when visual input was removed. Additionally, greater knee flexion angle at initial contact for the right leg, greater maximum VGRF for the left leg, greater time lag to maximum ankle dorsiflexion for the left leg, and greater time lag elapsed to maximum VGRF for the left leg were identified when the Soldiers were blindfolded. The observed biomechanical changes may be associated with increased risk of lower body musculoskeletal injuries.

Under the NV condition, Soldiers demonstrated greater hip abduction angles bilaterally. Without a significant difference in the knee varus angle, the greater hip abduction was likely a strategy to expand the base of support in the medial-lateral direction. If the center of mass falls outside of

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4 such area, posture is unstable and the risk of fall increases. Therefore, expanding the base of  
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6 support reduces the risk of fall and is beneficial for maintaining postural stability. Without visual  
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8 input, it may be possible that Soldiers attempt to drop and land more cautiously, resulting in  
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10 unconscious increased abduction of the hips thereby widening the base of support. A post hoc  
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12 analysis was performed and demonstrated greater distance between the ankle joint centers in the  
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14 medial-lateral direction ( $p < 0.001$ ). While the base of support between the feet increased by 3.5%,  
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16 it cannot be determined if such increase had any clinical significance on posture stability.  
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22         The VGRF induced by landing impact are transferred up through the ankles, knees, and  
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24 hips and require significant eccentric muscle contraction for stabilization and suppression of  
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26 forces. The VGRF create external dorsiflexion torque at the ankles, and external flexion torques  
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28 at the knees and hips. The ankle plantar flexors, knee extensors, and hip extensors contract  
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30 eccentrically to resist the external torques, maintaining the stability of the lower extremity. At the  
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32 knee joint, the contraction of the quadriceps creates an anterior shear force at the proximal tibia,  
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34 placing stress at the anterior crucial ligament (ACL).<sup>24</sup> Increased tibial anterior shear force is  
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36 related to increased knee extension torque.<sup>8</sup> Therefore, reducing VGRF is considered essential  
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38 for preventing non-contact ACL injuries. Previous work demonstrated that increased ankle  
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40 plantar flexion angle at initial contact was related to decreased VGRF.<sup>10</sup> In addition, increasing  
41  
42 knee flexion angle at initial contact and allowing greater knee flexion throughout the landing are  
43  
44 surmised to reduce VGRF.<sup>25, 26</sup> In the current study, no significant difference was found between  
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46 conditions in ankle plantar flexion at initial contact. However, the maximum knee flexion angles  
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48 were smaller when visual input was not available. That is, Soldiers flexed their knees less  
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50 throughout the landing under the NV condition, similar to that reported by Santello et al.<sup>16</sup> The  
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52 current result suggests that removing the visual input may reduce Soldiers' VGRF dissipation.  
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4 The mechanism leading to this decreased maximum knee flexion is unclear. It may be a cautious  
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6 move as people tend to reduce the range of movement and move more carefully in the dark. With  
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8 decreased knee flexion, the center of mass of the body is maintained higher with less vertical  
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10 fluctuation. The decreased knee flexion may suggest increased joint stiffness, attributed to  
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12 increased stiffness of muscles surrounding the knee.<sup>27</sup> Increased muscle stiffness are due to  
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14 increased muscle activation level, indicating the muscles are pre-loaded and ready to contract.<sup>27</sup>  
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16 Both the less-perturbated center of mass and increased muscle stiffness may help Soldiers to be  
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18 more reactive to unexpected events and ready for the next move during tactical operations.  
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25 With decreased maximum knee flexion angles, one may expect to see greater VGRF under the  
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27 NV condition. However, maximum VGRF increased significantly only for the left leg, with an  
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29 18% BW average increase. Recent computer model simulation demonstrated that a 12%BW  
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31 increase in VGRF resulted in a 9%BW increase in ACL force.<sup>28</sup> The mechanism behind such an  
32  
33 asymmetric change in VGRF is unclear. Bilateral comparisons have not been addressed in  
34  
35 previous studies investigating visual input during drop landing because only unilateral data were  
36  
37 collected.<sup>15-18</sup> While the two-legged drop landing task is instructed to be symmetrical activity,  
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39 asymmetric kinematic and force patterns were found in the current study. For both the WV and  
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41 NV conditions, the hips and knees were more extended resulting in a straightened right leg. A  
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43 straightened right leg suggests less energy dissipation following the impact. In addition, the right  
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45 foot may contact the ground earlier, and therefore assumes greater proportion of load at the  
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47 initial stage of landing when the left foot has not contact the ground yet. To verify, a post hoc  
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49 analysis was performed and found the right foot did contact the ground earlier (6ms,  $p=0.004$  for  
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51 WV and 5ms,  $p=0.015$  for NV). These kinematic asymmetries may partially explain the  
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53 significantly greater VGRF at the right leg for both the WV and NV conditions. The significant  
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4 increase in the left leg VGRF under the NV condition suggested decreased bilateral difference in  
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6 VGRF with vision removed. This raised an interesting question that whether Soldiers dropped in  
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8 a more symmetric manner without vision. The right knee flexion at initial contact increased  
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10 significantly when visual input was removed, although the angle was still significantly smaller  
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12 than the left knee. By flexing the knees more symmetrically, the distribution of impact might be  
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14 more balanced across the two legs, and the VGRF might be more comparable between each leg,  
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16 as the Soldiers demonstrated under the NV condition.  
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22 In the current study, no bilateral difference or between-condition differences were found in ankle  
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24 plantar flexion angles at initial contact or maximum ankle dorsiflexion angles. However, with  
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26 visual input removed, the time elapse from initial contact to maximum ankle dorsiflexion was  
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28 shorter for the left leg than the right leg. In addition, this elapsed time for the left leg was shorter  
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30 under the NV condition. Decreased time elapsed indicates shorter time the ankle joint had for  
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32 dissipating the VGRF through dorsiflexion. As result, the loading rate of forces applied on the  
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34 ankle joint may increase, affecting postural stability and increasing the risk of damage in  
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36 surrounding tissues. The shorter time reaching maximum dorsiflexion at the left ankle may  
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38 indicate less eccentric performance of the plantar flexors, limiting the capacity of energy  
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40 absorption. This may also partially explain the significant increase in the left leg VGRF.  
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46 However, with the ankle angles unchanged, the current evidence is not sufficient to support that  
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48 the removal of vision is associated with increased risk of ankle injury.  
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52 In summary, the current results suggested some potential mechanisms that theoretically could  
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54 contribute to the higher risk of injury during night operations in the US Army.<sup>11, 13</sup> Without  
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56 vision, decreased maximum knee flexion was identified, which was potentially due to increased  
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58 muscle stiffness surrounding the knee joint. While the increased knee joint stiffness may be  
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4 protective and can contribute to knee joint stability, it also reduces the knee's capacity of force  
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6 dissipation. Increased VGRF places greater risk of traumatic joint injuries such as strain, sprain,  
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8 or ligament rupture. Eccentric muscle activity at the left ankle resisting the external dorsiflexion  
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10 torque may not be appropriate, resulting in significantly increased VGRF at the left leg. Landing  
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12 with limited visual input in battlefield would be more dangerous than our standardized, practice-  
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14 allowed lab testing. The characteristics of terrain are unfamiliar, and Soldiers have to focus on  
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16 operation conditions instead of the task of landing itself. Plus, subjects did not carry weapons or  
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18 wear protection gears in the current study. In battlefield, the weight of equipment can further  
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20 place greater physical demands on Soldiers to perform landing tasks. The increased  
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22 unpredictability can potentially amplify the differences we found with a relatively more prepared  
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24 and planned movement. Altered knee kinematics and increased joint moments were found in  
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26 reactive compared with planned stop-jump tasks.<sup>7</sup> Furthermore, previous studies found increased  
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28 variability in EMG and kinematic patterns landing without vision.<sup>15, 16</sup> These may sum up into a  
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30 higher chance of inadequate neuromuscular activations when landing at night. Considering the  
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32 accompanied higher risk of night operation, it may be beneficial to develop training programs in  
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34 attempt to improve Soldiers' kinematic and neuromuscular performance when vision is affected.  
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36 It is unclear, however, whether kinematic or muscle activation patterns during landing can be  
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38 trained to override the lack of visual input. An intervention program conducted on Air Assault  
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40 Soldiers demonstrated that posture sway in anterior/posterior and medial/lateral directions under  
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42 no-vision condition can be reduced via balance training with eyes-closed.<sup>29</sup> It is also unclear  
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44 whether such improvements are sustainable. Future research is encouraged to study the design  
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46 and efficacy of potential training programs with vision deprived. Finally, increased body weight  
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48 or body mass index (BMI) in military recruits may result in early discharge and higher risk of  
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4 injury. Increased body weight or BMI in military recruits have been a concern in the US Army.  
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6 Future research is needed to evaluate whether the potential detrimental effects of the detected  
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8 biomechanical differences further increase with increased body weight.  
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11 The current study has its limitations. All subjects performed the WV condition first, practiced  
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13 before real trials, and were blindfolded for the NV condition after they stepped onto the platform.  
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15 As the height of the platform remained unchanged in this study, such design raises two potential  
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17 issues. The first is potential practice effects. In a previous study, Santello et al. tested subjects for  
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19 the NV condition first, varied the platform height, and blindfolded the subjects before stepping  
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21 onto the platform.<sup>16</sup> No practice effects in kinematics or VGRF were found across trials in either  
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23 WV or NV condition.<sup>16</sup> Magalhaes and Goroso found the first drop landing trial with vision  
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25 removed induced pre-landing EMG adaptations for the following trials, making muscle  
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27 activation patterns similar to that observed with vision.<sup>30</sup> However, Santello et al. suggested no  
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29 such adaptation effect for both WV and NV conditions.<sup>16</sup> The second issue is that the subjects  
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31 were aware of the platform height. Liebermann and Goodman allowed their subjects to view the  
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33 height before dropping, and found unchanged or decreased VGRF and earlier muscle firings in  
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35 rectus femoris before initial contact.<sup>15, 18</sup> Santello et al., who detected increased VGRF and no  
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37 difference in muscle activation timings, argued that viewing the platform height in advance may  
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39 be used to plan the joint and muscle activation and compensate for the loss of visual input during  
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41 dropping.<sup>16</sup> Interestingly, our results of decreased maximum knee flexion and increased VGRF  
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43 were comparable to Santello et al.<sup>16</sup> while our design was more similar to Liebermann and  
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45 Goodman.<sup>15, 18</sup> Thus the current results do not support Santello's argument that viewing the  
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47 platform height is sufficient to compensate the removal of visual input. It is more likely that even  
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4 with some visual information gathered before dropping, the loss of vision still overrides an  
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6 existing movement plan.  
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10 This research is among few studies investigating the effect of visual input on biomechanics of  
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12 landing, and was the only study recruiting subjects from military populations. We expect the  
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14 results of this study will provide insights for improving Soldiers' training and injury prevention.  
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## 18 **Conclusion**

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22 Night-time operations are known of greater risk of injury than day-time. The removal of vision  
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24 alters Soldiers' landing kinematics and ground reaction forces, potentially placing them under  
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26 higher risk. Physical training to compensate for night-specific tasks is needed for Soldiers to  
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28 establish a motor program of proper landing skills, and therefore reduce the effect of limited  
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30 visual input.  
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42 conclusions and recommendations are those of the author and are not necessarily endorsed by the  
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44 US Army.  
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## References

1. Sell TC, Chu Y, Abt JP, et al. Minimal additional weight of combat equipment alters Air Assault soldiers' landing biomechanics. *Mil Med.* 2010;175:41-47.
2. Hewett TE, Myer GD, Ford KR, Heidt Jr. RS, Colosimo MV, Succop P. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: A prospective study. *Am J Sports Med.* 2005;33(4):492-501.
3. Boden BP, Dean GS, Feagin JA. Mechanisms of anterior cruciate ligament injury. *Orthopedics.* 2000;23:573-578.
4. Decker MJ, Torry MR, Wyland DJ, Sterett WI, Steadman JR. Gender differences in lower extremity kinematics, kinetics, and energy absorption during landing. *Clin Biomech.* 2003;18:662-669.
5. Lephart SM, Ferris CM, Riemann BL, Myers JB, Fu FH. Gender differences in strength and lower extremity kinematics during landing. *Clin Orthop.* 2002;401:162-169.
6. Rozzi SL, Lephart SM, Fu FH. Effects of muscular fatigue on knee joint laxity and neuromuscular characteristics of male and female athletes. *J Athl Train.* 1999;34(2):106-114.
7. Sell TC, Ferris CM, Abt JP, et al. The effect of direction and reaction on the neuromuscular and biomechanical characteristics of the knee during tasks that simulate the non-contact ACL injury mechanism. *Am J Sports Med.* 2006;33:263-271.
8. Sell TC, Ferris CM, Abt JP, et al. Predictors of proximal anterior tibia shear force during a vertical stop-jump. *J Orthop Res.* 2007;25(12):1589-1597.



- 1  
2  
3  
4 **9.** Kaufman KR, Brodine S, Shaffer R. Military training-related injuries: Surveillance,  
5  
6 research, and prevention. *Am J Prev Med.* 2000;18(3S):54-63.  
7  
8
- 9 **10.** Whitting JW, Steele JR, Jaffrey M, Munro BJ. Does foot pitch at ground contact affect  
10  
11 parachute landing technique? *Mil Med.* 2009;174(8):832-837.  
12  
13
- 14 **11.** Glorioso JE, Batts KB, Ward WS. Military free fall training injuries. *Mil Med.*  
15  
16 1999;164(7):526-530.  
17  
18
- 19 **12.** Ekeland A. Injuries in military parachuting: A prospective study of 4499 jumps. *Injury.*  
20  
21 1997;28(3):219-222.  
22  
23
- 24 **13.** Kragh Jr. JF, Jones BH, Amaroso PJ, Heekin RD. Parachuting injuries among Army  
25  
26 Rangers: A prospective study of an elite airborne battalion. *Mil Med.* 1996;161(7):416-  
27  
28 419.  
29  
30
- 31 **14.** Knapik JJ, Craig SC, Hauret KG, Jones BH. Risk factors for injuries during military  
32  
33 parachuting. *Aviat Space Environ Med.* 2003;74(7):768-774.  
34  
35
- 36 **15.** Liebermann DG, Goodman D. Pre-landing muscle timing and post-landing effects of  
37  
38 falling with continuous vision and in blindfold conditions. *J Electromyogr Kinesiol.*  
39  
40 2007;17:212-227.  
41  
42
- 43 **16.** Santello M, McDonagh MJN, Challis JH. Visual and non-visual control of landing  
44  
45 movements in humans. *J Physiol (Lond).* 2001;537.1:313-327.  
46  
47
- 48 **17.** Thompson HW, McKinley PA. Landing from a jump: the role of vision when landing  
49  
50 from known and unknown heights. *Neuroreport.* 1995;6:581-584.  
51  
52
- 53 **18.** Liebermann DG, Goodman D. Effects of visual guidance on the reduction of impacts  
54  
55 during landings. *Ergonomics.* 1991;34:1399-1406.  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

- 1  
2  
3  
4 **19.** Sell TC, Abt JP, Lovalekar M, et al. Warrior Model for Injury Prevention and Human  
5  
6 Performance - Eagle Tactical Athlete Program (ETAP) Part 1. *Journal Special*  
7  
8 *Operations Medicine*. 2010;10:2-21.  
9
- 10  
11 **20.** Woltring HJ. Smoothing and differentiation techniques applied to 3-D data. In: Allard P,  
12  
13 Stokes IAF, Blanchi J-P, eds. *Three-dimensional analysis of human movement*.  
14  
15 Champaign, IL: Human Kinetics; 1994:79-100.  
16  
17
- 18  
19 **21.** Bell AL, Pederson DR, Brand RA. A comparison of the accuracy of several hip center  
20  
21 location prediction methods. *Journal of Biomechanics*. 1990;23:617-621.  
22
- 23  
24 **22.** Kadaba MP, Ramakrishnan HK, Gage JR. Measurement of lower extremity kinematics  
25  
26 during level walking. *Journal of Orthopaedic Research*. 1990;8:383-392.  
27
- 28  
29 **23.** Davis R, Ounpuu S, Tyburski D, Gage J. A gait analysis collection and reduction  
30  
31 technique. *Human Movement Science*. 1991;10:575-587.  
32
- 33  
34 **24.** Yu B, Garrett WE. Mechanisms of non-contact ACL injuries. *Br J Sports Med*.  
35  
36 2007;41(S1):i47-i51.  
37
- 38  
39 **25.** DeVita P, Skelly WA. Effect of landing stiffness on joint kinetics and energetics in the  
40  
41 lower extremity. *Med Sci Sports Exerc*. 1992;24(1):108-115.  
42
- 43  
44 **26.** Zhang SN, Bates BT, Defek JS. Contributions of lower extremity joints to energy  
45  
46 dissipation during landings. *Med Sci Sports Exerc*. 2000;32(4):812-819.  
47
- 48  
49 **27.** Riemann BL, Lephart SM. The sensorimotor system, part II: The role of proprioception  
50  
51 in motor control and functional joint stability. *J Athl Train*. 2002;37(1):80-84.  
52
- 53  
54 **28.** Laughlin WA, Weinhandl JT, Kernozek TW, Cobb SC, Keenan KG, O'Connor KM. The  
55  
56 effects of single-leg landing technique on ACL loading. *Journal of Biomechanics*. In  
57  
58 Press.  
59  
60  
61  
62  
63  
64  
65

- 1  
2  
3  
4 **29.** Abt JP, Sell TC, Lovalekar M, et al. Warrior Model for Injury Prevention and Human  
5  
6 Performance - Eagle Tactical Athlete Program (ETAP) Part 2. *Journal Special*  
7  
8 *Operations Medicine*. 2010;10:22-33.  
9  
10  
11 **30.** Magalhaes FH, Goroso DG. Preparatory EMG activity reveals a rapid adaptation pattern  
12  
13 in humans performing landing movements in blindfolded condition. *Percept Mot Skills*.  
14  
15 2009;109:500-516.  
16  
17  
18  
19  
20  
21  
22  
23  
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Figure Captions:

Figure 1. Drop landing with visual input

Figure 2. Drop landing without visual input

**Figure 1. Drop landing with visual input**  
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**Figure 2. Drop landing without visual input**  
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Table 1. Between-Condition and Bilateral Comparisons of Joint Angles, Vertical Ground Reaction Forces, and Timings

	Left Leg		Between	Right Leg		Between	Bilateral	
	(Mean±SD)		Condition	(Mean±SD)		Condition	Comparison	
			Comparison			Comparison	(p-value)	
	WV	NV	(p-value)	WV	NV	(p-value)	WV	NV
<i>Initial Contact</i>								
Hip Flexion (°)	22.8±7.0	22.6±7.9	0.492	21.4±6.8	21.2±8.0	0.654	<0.001	<0.001
Hip Abduction (°)	4.0±3.3	4.6±3.6	0.002	3.7±3.3	4.2±3.2	0.003	0.412	0.361
Knee Flexion (°)	20.0±6.0	20.0±5.7	0.775	18.1±6.2	18.7±5.8	0.046	<0.001	0.004
Knee Varus (°)	3.4±5.7	3.3±5.7	0.597	3.7±5.1	3.8±4.9	0.871	0.500	0.353
Ankle Plantarflexion (°)	19.8±9.0	20.0±7.7	0.641	19.3±7.9	19.3±7.5	0.725	0.273	0.142
<i>Maximum Values</i>								
Knee Flexion (°)	89.7±19.4	85.8±19.4	<0.001	88.6±19.3	85.4±19.5	<0.001	0.116	0.529
Ankle Dorsiflexion (°)	26.9±8.0	26.4±6.3	0.439	27.0±7.2	26.6±6.3	0.336	0.904	0.761
Vertical GRF (%BW)	341.9±96.4	359.9±89.4	<0.001	376.1±96.7	384.1±88.2	0.085	<0.001	<0.001
<i>Time to Max Values</i>								
Knee Flexion (ms)	240±115	236±113	0.618	234±81	238±120	0.600	0.346	0.807
Ankle Dorsiflexion (ms)	224±79	212±79	0.017	224±70	224±88	0.994	0.904	0.002
Vertical GRF (ms)	38±13	40±11	0.012	39±16	40±8	0.809	0.346	0.716

**Bold:** Significant Difference (p<0.05); BW: Body Weight; GRF: Ground Reaction Force

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# Abstract

Soldiers are subject to increased risk of musculoskeletal injuries in night operations due to limited visual input. The purpose of this study was to determine the effect of vision removal on lower extremity kinematics and vertical ground reaction forces (VGRF) during two-legged drop landings. The researchers tested 139 Air Assault Soldiers performing a landing task with and without vision. Removing visual input resulted in increased hip abduction at initial contact, decreased maximum knee flexion, and increased maximum VGRF. Without vision, the timing of maximum ankle dorsiflexion for the left leg was earlier than the right leg. The observed biomechanical changes may be related to the increased risk of injury in night operations. Proper night landing techniques and supplemental training should be integrated into Soldiers’ training to induce musculoskeletal and biomechanical adaptations to compensate for limited vision.



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***Institutional Review Board***

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Pittsburgh, PA 15213  
(412) 383-1480  
(412) 383-1508 (fax)  
<http://www.irb.pitt.edu>

**Memorandum**

To: [Timothy Sell](#) PhD  
From: [Margaret Hsieh](#) MD, Vice Chair  
Date: 12/6/2011  
IRB#: [REN11110088](#) / PRO08060158  
Subject: Validation and implementation of an injury prevention and performance optimization training program

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The Renewal for the above referenced research study was reviewed and approved by the Institutional Review Board, Committee H, which met on 11/30/2011.

Please note the following information:

The risk level designation is [Greater Than Minimal Risk](#).

Approval Date: 11/30/2011  
Expiration Date: 11/29/2012

Please note that it is the investigator's responsibility to report to the IRB any unanticipated problems involving risks to subjects or others [see 45 CFR 46.103(b)(5) and 21 CFR 56.108(b)]. The IRB Reference Manual (Chapter 3, Section 3.3) describes the reporting requirements for unanticipated problems which include, but are not limited to, adverse events. If you have any questions about this process, please contact the Adverse Events Coordinator at 412-383-1480.

The protocol and consent forms, along with a brief progress report must be resubmitted at least **one month** prior to the renewal date noted above as required by FWA00006790 (University of Pittsburgh), FWA00006735 (University of Pittsburgh Medical Center), FWA00000600 (Children's Hospital of Pittsburgh), FWA00003567 (Magee-Womens Health Corporation), FWA00003338 (University of Pittsburgh Medical Center Cancer Institute).

**Please be advised that your research study may be audited periodically by the University of Pittsburgh Research Conduct and Compliance Office.**



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**Memorandum**

To: [Scott Lephart](#)  
From: [Ron Shapiro](#) , Vice Chair  
Date: 12/12/2011  
IRB#: [REN11110087](#) / IRB0506094  
Subject: Injury Prevention and Performance Enhancement in 101st Airborne Soldiers

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The Renewal for the above referenced research study was reviewed and approved by the Institutional Review Board, Committee A, which met on 12/6/2011.

As per our discussion regarding the modification to this study which is to submitted after this renewal is approved:

1. Please upload the grant.
2. Please list Dr. Stone as the independent medical monitor for the DSMP.
3. Attach the paper version of the scientific approval under "Other Attachments".

Please note the following information:

The risk level designation is [Greater Than Minimal Risk](#).

Approval Date: 12/6/2011  
Expiration Date: 12/5/2012

Please note that it is the investigator's responsibility to report to the IRB any unanticipated problems involving risks to subjects or others [see 45 CFR 46.103(b)(5) and 21 CFR 56.108(b)]. The IRB Reference Manual (Chapter 3, Section 3.3) describes the reporting requirements for unanticipated problems which include, but are not limited to, adverse events. If you have any questions about this process, please contact the Adverse Events Coordinator at 412-383-1480.

The protocol and consent forms, along with a brief progress report must be resubmitted at least **one month** prior to the renewal date noted above as required by FWA00006790 (University of Pittsburgh), FWA00006735 (University of Pittsburgh Medical Center), FWA00000600 (Children's Hospital of Pittsburgh), FWA00003567 (Magee-Womens Health Corporation), FWA00003338 (University of Pittsburgh Medical Center Cancer Institute).

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DEPARTMENT OF THE ARMY  
HEADQUARTERS, DWIGHT DAVID EISENHOWER ARMY MEDICAL CENTER  
300 E. HOSPITAL ROAD  
FORT GORDON, GEORGIA 30905-5650

REPLY TO  
ATTENTION OF:

MCHF-CI

14 Feb 12

MEMORANDUM FOR COL Mike Wirt, MC

SUBJECT: Continuing Review Approval for the Protocol, "Injury Prevention and Performance Enhancement in 101st Airborne Soldiers" Submitted by John Abt, PhD, Blanchfield Army Community Hospital, Ft Campbell, KY, DDEAMC 07-16, [351386-14]

1. The subject greater than minimal risk protocol was initially approved by the Dwight D. Eisenhower Army Medical Center (DDEAMC) Institutional Review Board (IRB) on 11 Jan 07.
2. The protocol and submitted continuing review report were reviewed by the DDEAMC IRB at the 12 Jan 12 meeting and found to be in compliance with Federal, DOD, and U.S. Army human subjects protection requirements. The protocol is re-approved for a period of one year, 12 Jan 12 – 11 Jan 13.
3. The stamped informed consent document (version 4 Oct 11) and the HIPAA Authorization submitted on 6 Oct 11 should be used when consenting subjects.
4. In accordance with 32 CFR 219.109(e), the protocol must be reviewed for continuation by the DDEAMC IRB no later than 11 Jan 13. A continuing review report with a copy of the current protocol and Consent Form must be submitted by 15 Nov 12 to ensure approval on or before 11 Jan 13.
5. The Principal Investigator remains responsible for fulfilling reporting requirements to the DDEAMC IRB as outlined in the Investigator Responsibilities agreement.

COLIN C. EDGERTON  
MAJ, MC  
Chair, Institutional Review Board

"This document has been electronically signed in accordance with all applicable regulations, and a copy is retained within our records."



DEPARTMENT OF THE ARMY  
HEADQUARTERS DWIGHT DAVID EISENHOWER ARMY MEDICAL CENTER  
FORT GORDON, GEORGIA 30905-5650

REPLY TO  
ATTENTION OF:

MCHF-CI

27 Dec 11

MEMORANDUM FOR COL Michael Wirt, MC

SUBJECT: Continuing Review Approval for the Protocol, "Validation and Implementation of an Injury Prevention and Performance Optimization Training Program" Submitted by COL Michael Wirt, MC, BACH, Ft Campbell, KY, DDEAMC 08-36, [351385-15]

1. The subject greater than minimal risk protocol was initially approved by the Dwight D. Eisenhower Army Medical Center (DDEAMC) Institutional Review Board (IRB) on 8 May 08.
2. The protocol and submitted continuing review report were reviewed by the DDEAMC IRB at the 8 Dec 11 meeting and was granted conditional approval. The requested revisions to the protocol were received on 14 Dec 11 and were reviewed and approved by the designated reviewer on 22 Dec 11. The protocol is re-approved for a period of one year, 22 Dec 11 – 21 Dec 12.
3. The stamped informed consent document Aim 1 (version 4 Oct 11) and Aim 2 (version 4 Oct 11), and HIPAA Authorization (dated 6 Aug 11) should be used when consenting subjects.
4. In accordance with 32 CFR 219.109(e), the protocol must be reviewed for continuation by the DDEAMC IRB no later than 21 Dec 12. A continuing review report with a copy of the current protocol and Consent Form must be submitted by 15 Oct 12 to ensure approval on or before 21 Dec 12.
5. The Principal Investigator remains responsible for fulfilling reporting requirements to the DDEAMC IRB as outlined in the Investigator Responsibilities agreement.

COLIN C. EDGERTON  
MAJ, MC  
Chair, Institutional Review Board

"This document has been electronically signed in accordance with all applicable regulations, and a copy is retained within our records."